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AN EXPERIMENTAL INVESTIGATION OF THE CIRCULAR DISC ANTENNA.(U)

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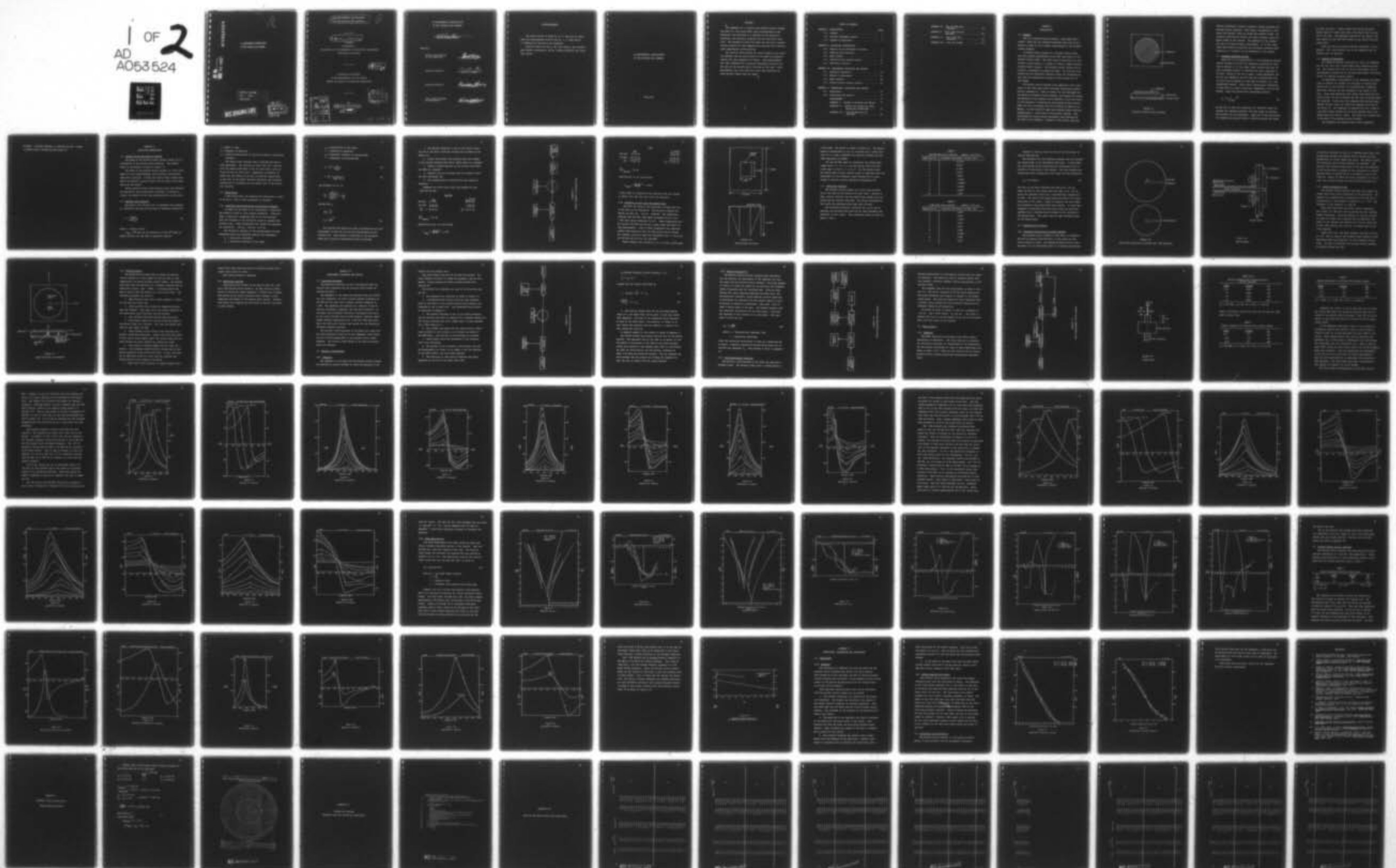

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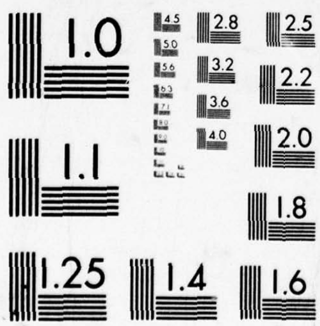

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AN EXPERIMENTAL INVESTIGATION OF THE CIRCULAR DISC ANTENNA

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AN EXPERIMENTAL INVESTIGATION

OF THE CIRCULAR DISC ANTENNA

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AN EXPERIMENTAL INVESTIGATION OF THE CIRCULAR DISC ANTENNA

July 1976

ABSTRACT

The impedance of a circular disc printed circuit antenna and that of a full scale model using polystyrofoam as the dielectric were measured as a function of the dielectric thickness, the operating frequency and the feed point location. The impedance of both the model and the actual printed circuit antenna was then compared with existing data from previous experimental investigations.

The electric field inside the cavity formed by the circular radiator and the ground plane of the model was measured varying the same parameters as before. These measurements were then compared with a previous theoretical analysis for the case of the antenna fed at the edge of the disc. Field measurements were also taken for other feed positions for which present theory does not apply.

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CHAPTER I

INTRODUCTION

1-1 History

What is a printed circuit antenna? From where did it evolve? These are two important questions that must be answered in order to get a better understanding of the printed circuit antenna.

A printed circuit antenna is a printed circuit board with the radiator photoetched on one side (the outer) of the printed circuit board. The other side of the board is a solid metal ground plane.[1] Figure 1-1 shows a simple circular printed circuit antenna. The printed circuit antenna can be circular, rectangular or square in shape. The circular disc antenna was the particular radiator chosen for investigation and, thus all drawings and samples in this thesis will be that shape.

The printed circuit antenna first appeared in the literature in 1972 when John Howell discussed rectangular printed circuit antennas.[2] Since no theory had been developed for the design of printed circuit antennas, the process for design and matching of the antenna was by necessity, trial and error. In 1974 Munson[3] introduced the wrap-around printed circuit board for use on missiles, but still offered no theory as to design. In 1975 Howell[4] again gave further design criteria, concentrating a little more on the circular antenna. This time Howell[4] offered design procedures after determining the size of the radiator. Finally in 1976, Morel, Long and

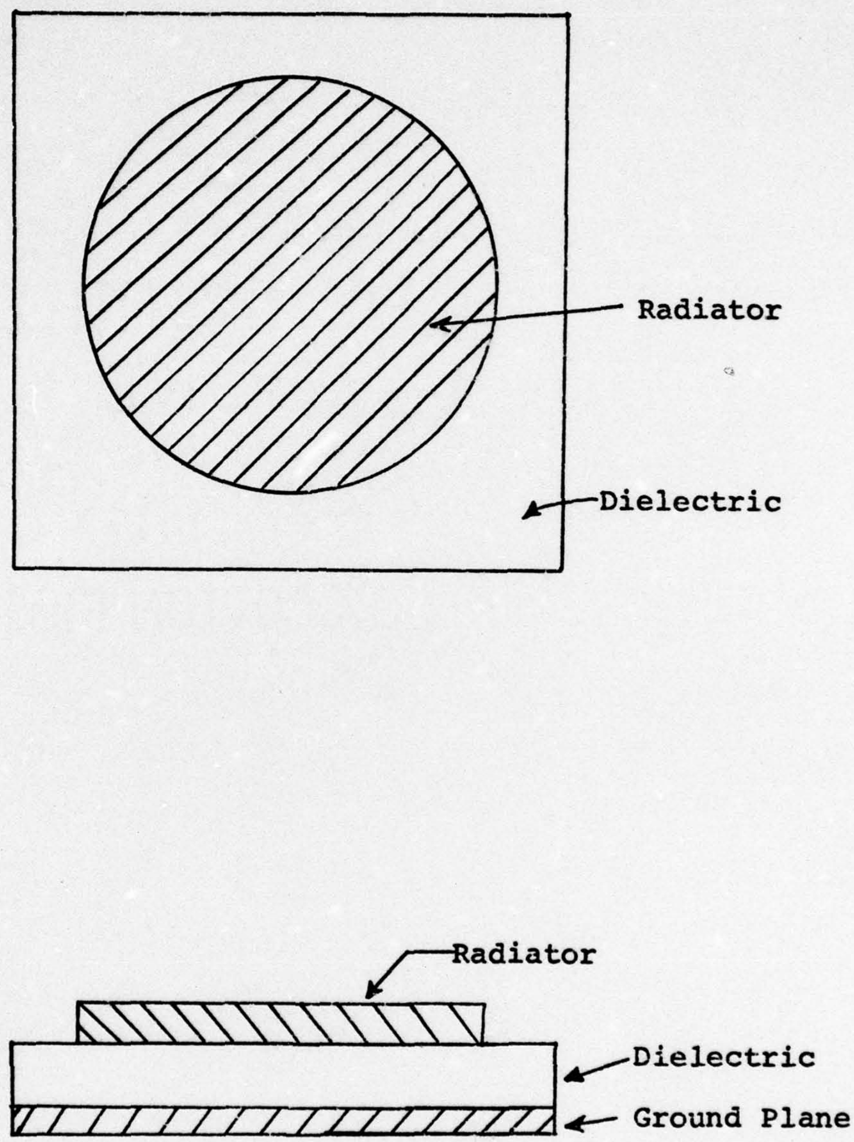


Figure 1-1

Circular Printed Circuit Antenna

Shen[5] introduced a theory to provide a design procedure for printed circuit antennas. This theory, as applied to a circular disc antenna, used the fields and currents inside the cavity to find the far fields, the total radiated power and power losses in the antenna. The impedance of the antenna has yet to be theoretically investigated. It is this impedance which shall be carefully and thoroughly examined experimentally as a function of the parameters of the antenna.

1-2 Previous Impedance Results

Howell[2] in his investigation of the rectangular printed circuit antenna did little for impedance determination other than to measure it at the signal input location and then design a matching network to transform the input impedance to 50 ohms. Munson[3] did try to apply a rough approximate theory for the impedance, but his case was so specialized that it could only be applied to that type of antenna, i.e., the wrap-around antenna. Munson used a quarter-wave transformer to step down his various feed point impedances to the 50 ohms needed. Using the quarter-wave transformer equation

$$Z_t = (Z_{in} Z_{out})^{1/2} \qquad (1)$$

he was able to make the transition.[3] Howell[4] again addressed the impedance problem, this time using the circular disc antenna for his experiment. Again the 50 ohm match point for feeding the antenna without a matching network was found

by trial and error. Howell states that the 50 ohm match should occur at a point near 32% of the radius from the center of the disc. The impedance measured at the edges of the disc should be very high while those at the center would approach zero.

These are the only previous results concerning the impedance. Now a more careful look at the impedance and its effects shall be explored.

1-3 Purpose of Experiment

The radiation pattern, polarization, gain, and impedance are the four most often investigated areas concerning antennas. This thesis shall look at one of these areas, that of the impedance, closely and at the same time observe the fields within the antenna structure itself.

An experimental investigation of the impedance was undertaken to observe its changes as a function of various parameters such as the thickness of the dielectric, frequency, feed point location and the grounding of the center of the disc. These same parameters were varied while observing the fields within the cavity between the disc and the ground plane. The impedance results are then compared with previous experimental results, while the fields are compared with that of the theory.[5] The impedance is measured for both a model of a printed circuit antenna and on actual printed circuit antennas made from circuit board. The fields are measured only on the model of the printed circuit antenna.

The impedance was measured using three independent

methods: a network analyzer, a slotted line and a vector voltmeter with a voltage-current probe.[6]

CHAPTER II

DESIGN AND CONSTRUCTION

2-1 General Set Up and Shape of Antenna

The shape of the printed circuit antenna chosen for investigation is the circular disc structure. The general shape of the antenna is shown in Figure 1-1.

The model of the printed circuit antenna is a full scale model but with interchangeable disc radiators and multiple feed point locations. A model was used so that as many parameters as possible could be varied for the study of the impedance and the fields.

Actual printed circuit board antennas were also designed and fabricated using photetching techniques to conform as closely as possible to the same characteristics as the model.

2-2 Radiator Size Selection

The size of the circular disc is dependent upon frequency, dielectric constant and the mode of operation desired.[4]

$$a = \frac{X'_{mn}c}{2\pi f(\varepsilon_r)^{\frac{1}{2}}} \tag{2}$$

where a = radius of disc

X'_{mn} = m^{th} zero of the derivative of the n^{th} order of Bessel function for the mode of operation desired.

c = speed of light

f = frequency of operation

ε_r = relative permittivity of dielectric material (dielectric constant)

The lowest order resonant mode is desired and used in this experiment. The theory[5,8] shows that for a circular disc the lowest order mode is the n=1 mode with a value of $X'_{11}=1.84$ for its first zero. Inspection of equation (2) shows that the radius of the disc is directly proportional to the zero of the Bessel function derivative and inversely proportional to frequency and the square root of the dielectric constant.

2-3 Model Design

A full scale model was designed and constructed in order to be able to vary as many parameters as possible.

2-3a Selection and Determination of Dielectric Constant

In order for the model to be constructed, a dielectric was needed in order to start design procedures. Polystyrofoam, a dielectric resembling that of air was selected. Thus the thickness of the dielectric could be changed with relative ease. Three thicknesses were chosen for experimental evaluation: .635 cm., .953 cm., 1.27 cm.

The dielectric constant of the polystyrofoam was then determined using the following formulas and techniques:

λ_o = free space wavelength

ε_o = dielectric constant of free space

μ_o = permeability of free space

f = frequency of operation

ε_r = dielectric constant of polystyrofoam

λ = wavelength in polystyrofoam

$$\lambda_o = \frac{c}{f} = \frac{1}{\sqrt{\mu_o \varepsilon_o}\, f} \tag{3}$$

$$\lambda = \frac{v}{f} = \frac{1}{\sqrt{\mu_o \varepsilon_o}\ \sqrt{\varepsilon_r}\ f} \tag{4}$$

now dividing (4) by (3)

$$\frac{\lambda}{\lambda_o} = \frac{\dfrac{1}{\sqrt{\mu_o \varepsilon_o \varepsilon_r}\ f}}{\dfrac{1}{\sqrt{\mu_o \varepsilon_o}\ f}} = \frac{1}{\sqrt{\varepsilon_r}}$$

solving for ε_r

$$\sqrt{\varepsilon_r} = \frac{\lambda_o}{\lambda}$$

$$\varepsilon_r = \left(\frac{\lambda_o}{\lambda}\right)^2 \tag{5}$$

The slotted line method was used in determining the half-wavelengths in both the air and the polystyrofoam filled slotted line. This process is described in the following steps and is good for determining either wavelength.

1. The desired frequency is set on the signal source and fed to the short circuited slotted line as shown by the Figure 2-1.

2. Obtain the slotted line position when the reading on the Voltage Standing Wave Ratio (VSWR) meter is a minimum.

3. Obtain a second position on the slotted line where the VSWR is a minimum.

4. Subtract the first minimum from the second to give the half wavelength ($\frac{\lambda}{2}$).

5. New readings must be obtained for each change in frequency.

Examples are given below using this method for both 1 GHZ and 600 MHZ.

<u>600 MHZ</u>

	air	ε_r filled
2nd min:	33.1 cm.	28.45 cm.
1st min:	8.28 cm.	3.68 cm.
	$\frac{\lambda_o}{2}$ = 24.82 cm.	$\frac{\lambda}{2}$ = 24.77 cm.

$$\left(\frac{\lambda_o}{2}\right)_{theory} = 25 \text{ cm.}$$

substituting into (5) and solving

$$\varepsilon_{r_{600}} = \left(\frac{49.64}{49.54}\right)^2 = 1.004$$

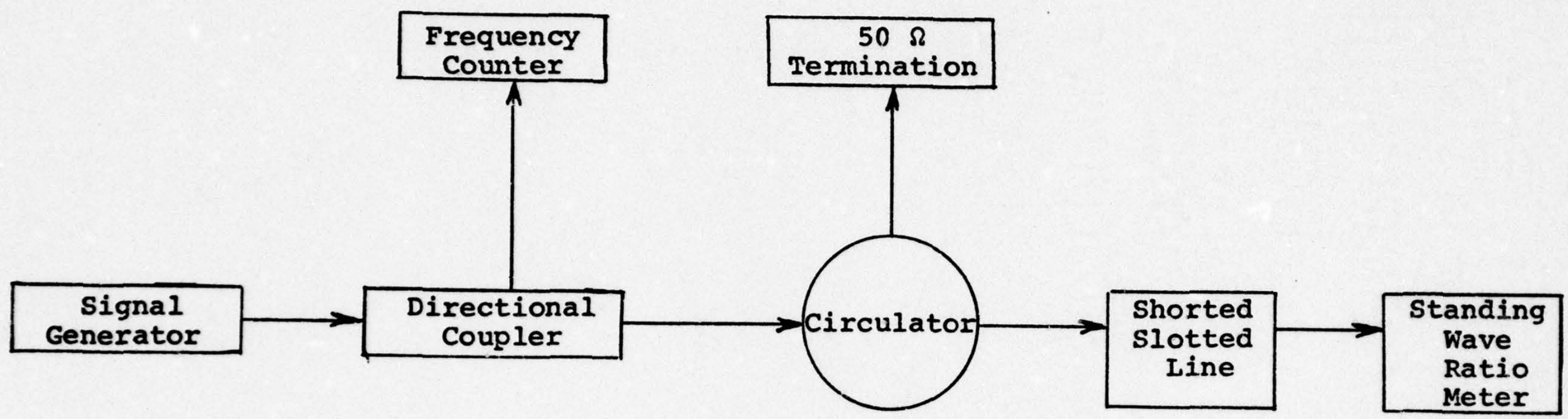


Figure 2-1

Block Diagram of Slotted Line

1 GHZ

	air	ε_r filled
2nd min:	27.74 cm.	27.88 cm.
1st min:	-12.71 cm.	-12.96 cm.
	$\frac{\lambda_o}{2}$ = 15.03 cm.	$\frac{\lambda}{2}$ = 14.92 cm.

$$\left(\frac{\lambda_o}{2}\right)_{theory} = 15 \text{ cm.}$$

Substituting in (5) and solving:

$$\varepsilon_{r_{1000}} = \left(\frac{30.06}{29.84}\right)^2 = 1.01479$$

A wide range of frequencies were measured with the average ε_r being 1.014 and thus this value was selected.

2-3b Selection of Disc Size and Ground Plane

Now that the value of the dielectric is known the size of the disc can be determined. The material selected for making the disc was .159 cm. aluminum. The frequencies selected were 600 MHZ (free space wavelength 50 cm.) and 1 GHZ (free space wavelength 30 cm.). These frequencies will be varied $\pm$ 200 MHZ thus giving a large range over which to take measurements. Also at these frequencies the radiators remain large enough so that the feed points can be varied. The radiator sizes for these two frequencies are a = 14.54 cm. for 600 MHZ and 8.72 cm. for 1000 MHZ.

These antennas were mounted on a 9 x 12 foot ground plane

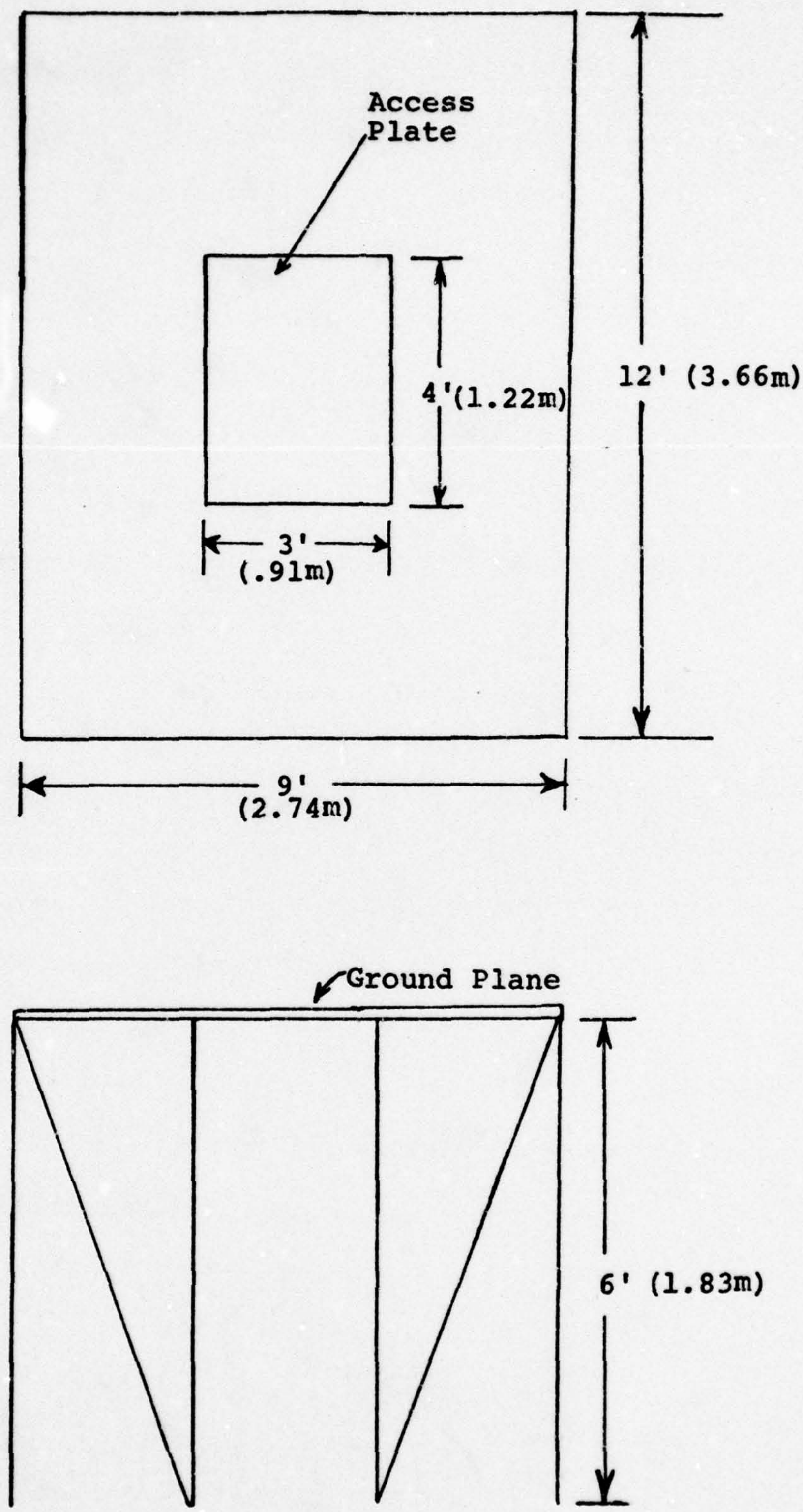


Figure 2-2

Ground Plane Structure

6 feet high. The system is shown in Figure 2-2. The ground plane is constructed of .635 cm. aluminum with a center section of 3 x 4 feet, removable for mounting antennas and any other apparatus as needed.

For the 600 MHZ range of frequencies the ground plane ranges from 5.7 λ to 7.3 λ for the shorter side while the 1 GHZ range is from 7.3 λ to 11.0 λ for the shorter side. The ground plane clearly remains large in comparison with the wavelength for the frequency ranges desired and is large enough to provide accurate impedance measurements.[6]

2-3c <u>Feed Point Location</u>

The printed circuit antenna up to this time had been fed at the edge of the radiator for most cases. Because of this, various locations for the feed points needed to be explored and the results tabulated. The theory developed for the fields was developed using edge feed criteria.

The following reference system was set up for use in graphing and recording data and will be used throughout the remainder of this thesis. This reference system is shown in Tables 1 and 2.

TABLE 1

600 MHZ Feed Point Location   Radius = 14.54 cm.

Feed Point No.	Distance from Center of Disc (cm.)
1	14.1175
2	12.918
3	11.483
4	10.101
5	8.664
6	7.1624
7	5.76326
8	4.2926
9	2.8829
10	1.493

TABLE 2

1 GHZ Feed Point Location   Radius = 8.72 cm.

Feed Point No.	Distance from Center of Disc (cm.)
1	8.382
2	8.072
3	7.0053
4	6.151
5	5.267
6	4.366
7	3.4366
8	2.565
9	1.651

Figure 2-3 gives an over all view of the feed point locations from the top.

The radiators for the different antennas were fed through the ground plane to the designated feed point. A feed assembly using GR-900 series connectors was constructed so as to provide a 50 ohm match to the antenna. The feed assembly was constructed using transmission line theory and the formula[9]:

$$Z_o = 60 \ln(b/a) \tag{6}$$

The size of the inner conductor was made to be .361 cm. while the hole in the ground plane was made to be .828 cm., giving the required ratios for a characteristic impedance of 50 ohms. The back of the ground plane was used as the reference point at all times. Figure 2-4 depicts the feed assembly attached to the ground plane and radiator. In later measurements a calibrated short was built using the same feed assembly with a shorting block attached at the location of the ground plane. This short gave the same reference point as the ground plane.

2-4 Printed Circuit Antenna

2-4a Previous Printed Circuit Antenna Designs

The printed circuit antenna is very small in thickness and the low profile characteristic is one reason for the great interest in them. The maximum thickness used to date has been 1.27 cm.[4]although there is no binding restriction

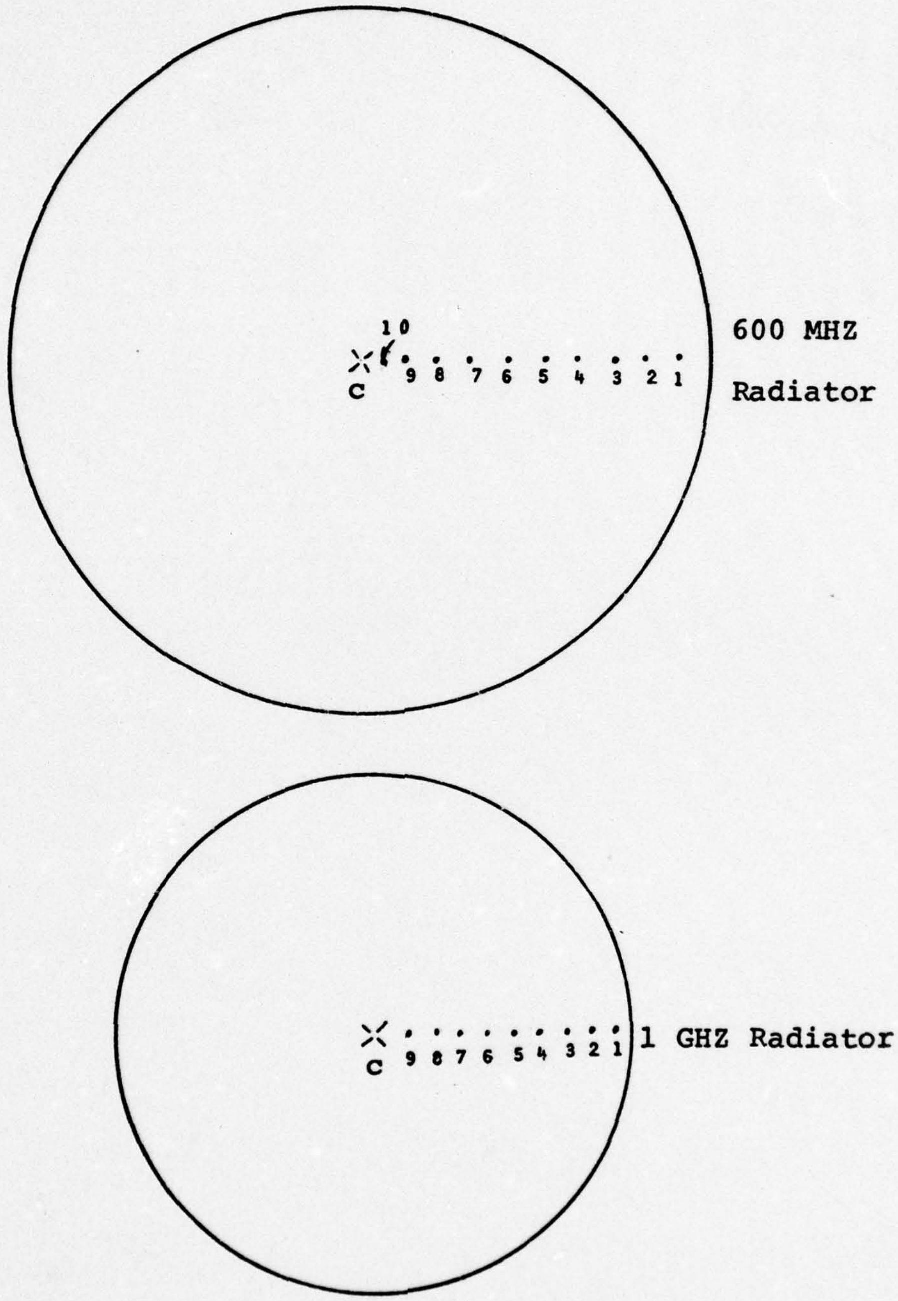


Figure 2-3

Feed Point Locations on 600 MHZ and 1 GHZ Radiators

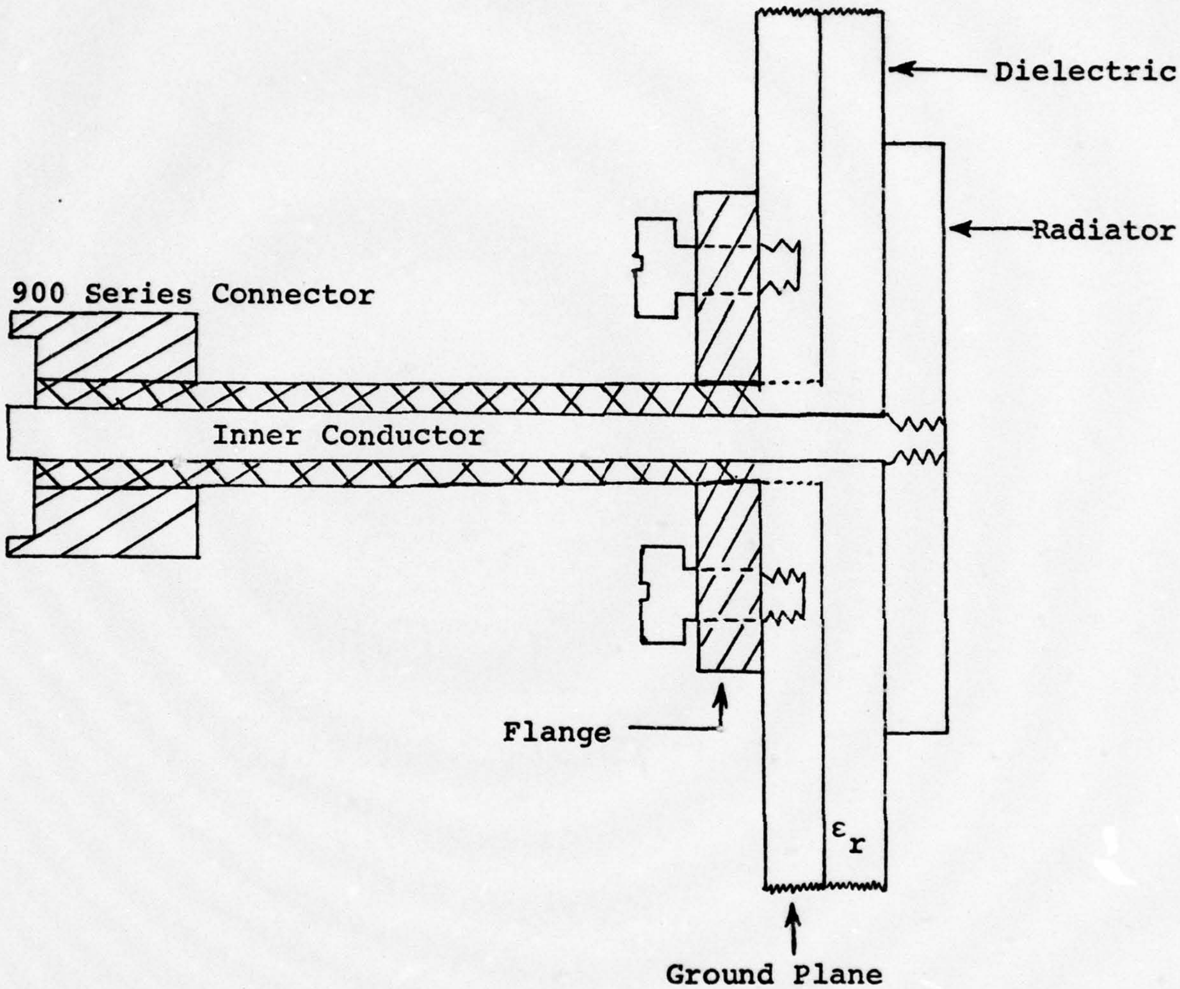


Figure 2-4

Feed Assembly

on absolute thickness as long as it remains electrically thin. As mentioned earlier the printed circuit antenna has been manufactured in various shapes and sizes. The design criteria for rectangular and circular antennas are different. The circular disc antenna studied here is fed from the underside of the ground plane as opposed to the recatangular or square radiator which is usually fed by a stripline at one of the sides.[4] Figure 2-5 shows the input arrangement of the circular disc printed antenna with the optional grounding pin.

2-4b Factors Determining Size

Two printed circuit antennas were made from copper laminated board using teflon fiberglass as the dielectric. The laminate was purchased from 3M Corporation and came with a certification of the dielectric constant of $\varepsilon_r = 2.47$. The thickness of the substrate is .1595 cm.

With these quantities now known, design frequencies were chosen at 1 GHZ and 2 GHZ to provide data for slightly higher frequencies. Using the formula (2) and the criteria of using the lowest order resonant mode of operation, the radius of the radiator was found to be 5.574 cm. while that of the 2 GHZ radiator was 2.787 cm. or exactly half of the 1 GHZ radiator.

Recall that the 1 GHZ model radiator size was 8.724 cm. or 1.56 times as large as the printed circuit antenna at the same design mode and frequency, but with different dielectrics. In order to fabricate the printed circuit antennas, an etching process was used.

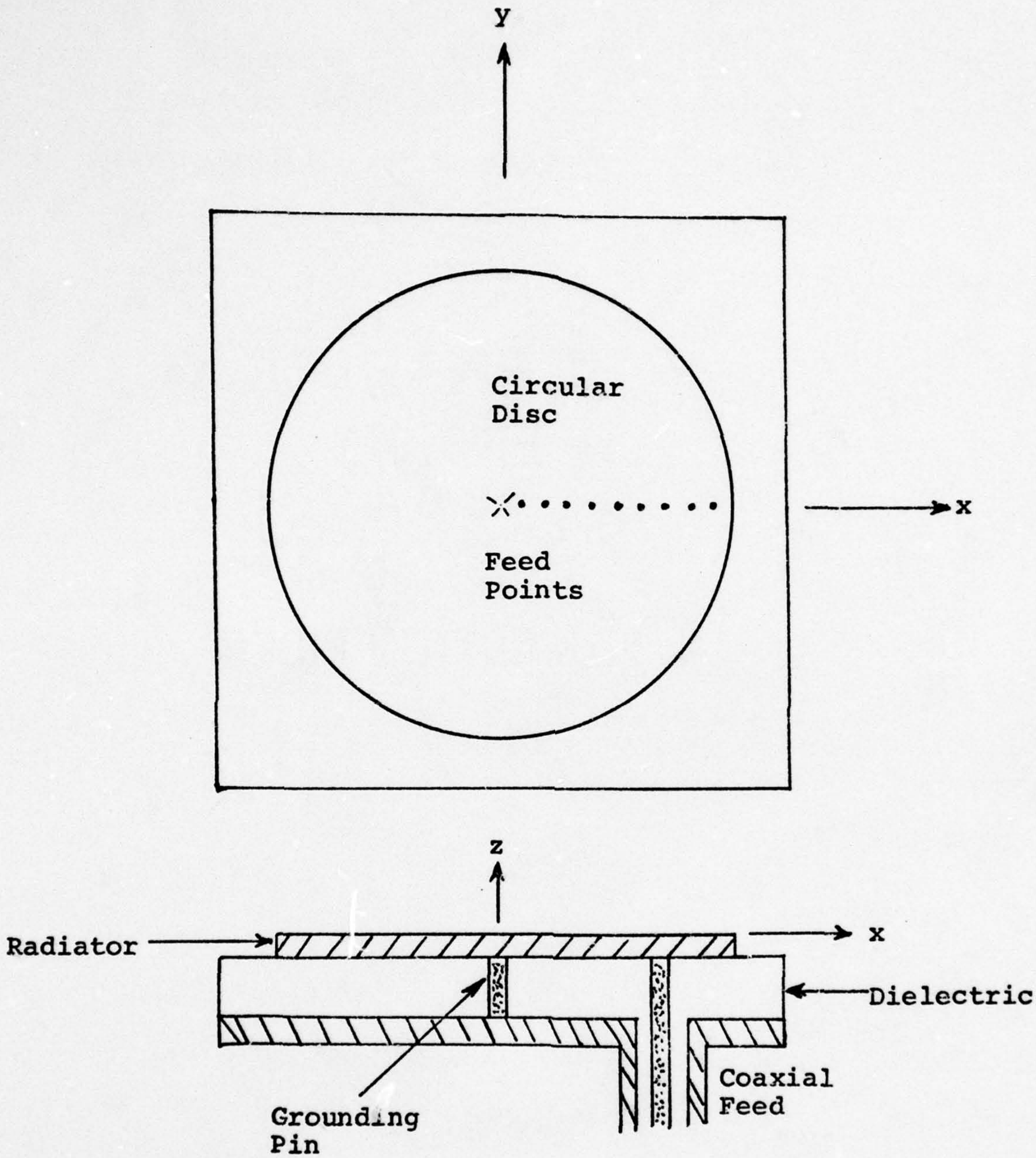


Figure 2-5

Input Structure for Antennas

2-4c Etching Process

The photoetching process used in making the printed circuit antenna is a very simple one and one that is used commercially for making printed circuit boards. The process must begin with the selection of a suitable chemical such as Kodak Photo Resist, Type 3 (KPR3). A coating mixture was made by mixing KPR3 and thinner in a one to one ratio. The following procedure was used:[7]

1. Make radiator shape from a photo negative or rubilyte and save for future use.

2. Clean printed circuit board by rubbing with steel wool and cleanser. This gets rid of any soiled condition on the board which could interfere with the process.

3. Coat surfaces with KPR3 mixture made previously.

4. Place photo negative on circuit board and expose to ultraviolet light for 5 minutes. Turn over and expose backside for same amount of time.

5. Place exposed circuit board in KPR developer for 2 minutes, agitating continously. Remove and rinse with water. A faint circle should appear where the circuit board was exposed through the photo negative by ultraviolet light.

6. Place board in etching chamber and set timer for 5 minutes. All unexposed copper should be etched away by the ferrous chloride at the end of this time. If not, set timer for an additional minute or until only the radiator and ground plane are left etched on the board.

7. Rinse with water and place in copper brighter for 1

minute then rinse again and place in plating solution until copper turns silver in color.

The etching process is complete.

2-5 Feed Point Location

Feed points were located at the edge on both the 1 GHZ and 2 GHZ printed circuit antenna. An edge feed was chosen mainly to verify the theory proposed in [5]and also to change feed points on the actual printed circuit antenna is very cumbersome and damage to the antenna often results. However, feed points were changed once and moved to the half way point on each antenna.

CHAPTER III

MEASUREMENT TECHNIQUES AND RESULTS

3-1 Quantities Measured

The quantities measured in this investigation were the driving point impedance and the electric field inside the antenna structure.

The impedance of the model was measured using two different size radiators, one with a design resonant frequency of 600 MHZ and the other with a design resonant frequency of 1 GHZ. The impedance was measured as a function of the dielectric thickness, frequency, and feed point location. On the model three different dielectric thicknesses were used. On the actual printed circuit board antenna, radiators whose design resonant frequencies were 1 GHZ and 2 GHZ were used. Again the feed point location was varied, but the dielectric thickness remained constant.

The electric fields measured on the model will again have the same parameters varied as for the impedance, while there will be no field measurement on the printed circuit board antennas. The electric field normal to the disc and ground plane was measured.

3-2 Methods of Measurement

3-2a Impedance

The impedance of the model and the printed circuit antenna was measured by several methods to check the accuracy of the

results and the systems used.

The first method used was the slotted line method. The block diagram in Figure 3-1 shows the equipment used in this method. Single minimum and double minimum methods were used.[6,10]

The slotted line technique was used in the following manner.[6]

1. The equipment was connected as shown in Figure 3-1.

2. A calibrated short-circuit with the same reference plane as the model or the printed circuit board antenna, was connected to the slotted line. The calibrated short-circuit is described in Chapter 2.

3. The desired frequency is set on the signal generator and the slotted line probe is adjusted for a maximum reading.[1] The voltage standing wave ratio (VSWR) meter is then adjusted for a VSWR reading of 1.

4. The slotted line probe with the short-circuit termination attached is then moved so as to obtain two minima on the VSWR meter. The position of each minimum is recorded.

5. These mimima allow the wavelength of the frequency used to be calculated.

6. The antenna is now attached to the slotted line and the measurements are taken, as in number 4 with the addition of the VSWR reading now also being recorded.

7. The following is then used to calculate the input impedance by the use of the Smith Chart.[10]

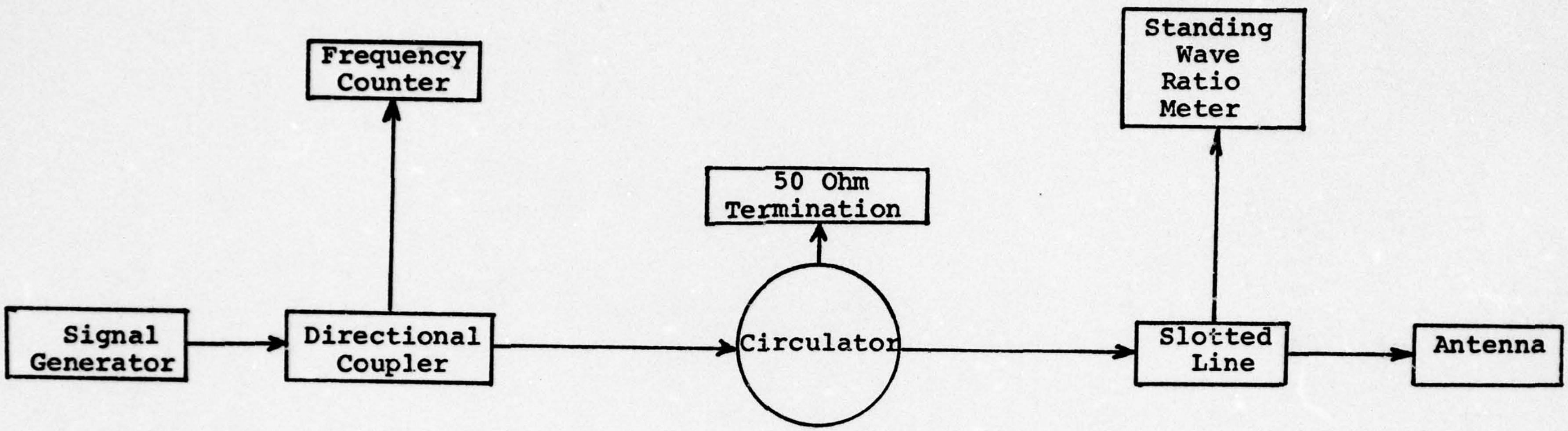


Figure 3-1

Slotted Line Block Diagram

$$a_1 (\text{antenna minimum}) - s_1 (\text{short minimum}) = \pm x$$

$$a_2 - s_2 = \pm \lambda \qquad (7)$$

average the two results and divide by

$$2 \cdot (s_1 - s_2) = \frac{\lambda_g}{2} \cdot 2 = \lambda_o \qquad (8)$$

$$\frac{\pm (x+y)}{2 \lambda_o} = \pm c \lambda_g \qquad (9)$$

8. Now with the answer from (9) and the VSWR reading taken in 6, the Smith Chart can be used to find the normalized impedance. The sign in (9) determines which direction to move on the Smith Chart. The positive (+) means to rotate toward the generator and the negative (-) means to rotate toward the load.[10]

A complete example of this method is shown in Appendix I.

The second slotted line method used was that of the double minimum. The equipment used is the same as in Figure 3-1 and the method of evaluation is the same as the single minimum except that instead of the reading being taken at the minimum for both the short-circuit and the antenna, readings are taken 3 db above and below the minimum. The two readings are then averaged and the process for finding the impedance is then the same as before with the single minimum.

3-2b Network Analyzer[11]

The Hewlett Packard network analyzer model 8410/8411A was the mainstay for measurement of the impedance for both the model and the printed circuit antennas. The block diagram in Figure 3-2 shows the system set up and gives the different types of displays used for recording data. Both the polar display CRT, which displays amplitude and phase data, and the phase-gain indicator, which displays relative amplitude in dB between the reference and test channel inputs or relative phase in degrees by push-button were used. This allowed a double check on the data. The network analyzer uses the reflection coefficient for its data output. From this the impedance of the antenna can be calculated. The impedance is given by:[12]

$$Z_L = Z_o\left(\frac{1+\Gamma}{1-\Gamma}\right) \qquad (10)$$

where Z_o = characteristic impedance (50Ω)

Γ = reflection coefficient

Since the reflection coefficient is given as a magnitude and an angle, a computer program was written which gives the resulting load impedance Z_L. This program is given in Appendix II.

3-2c Field Measurement Technique

The electric field measured on the model was done with a monopole probe. The monopole probe gives a reading which is

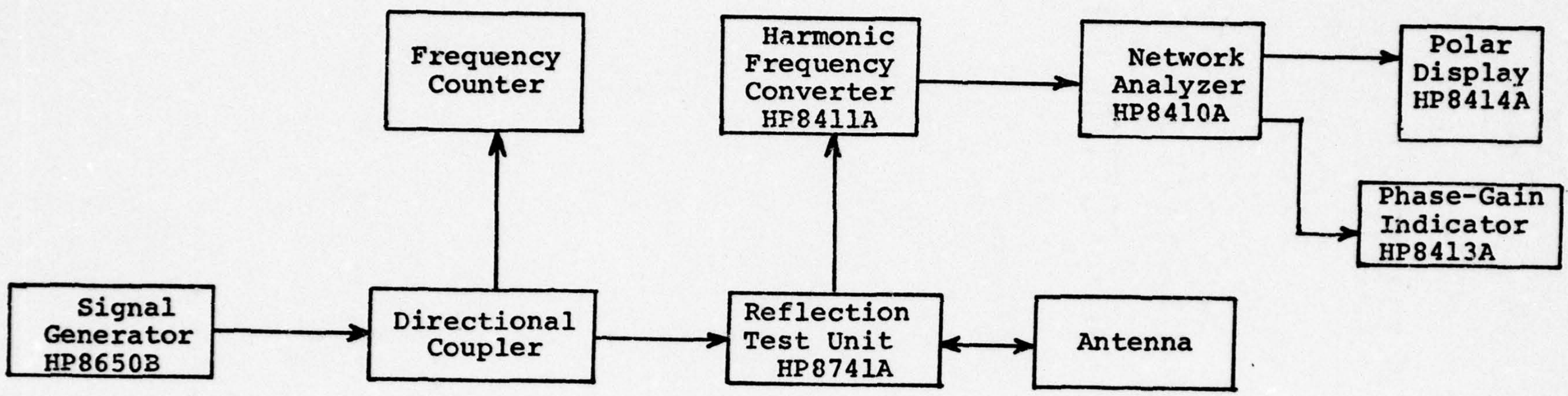


Figure 3-2

Block Diagram-Network Analyzer

directly proportional to the electric field inside the antenna structure. The probe will have an induced current that will produce a directly readable voltage proprotional to the electric field.

The equipment used for this measurement is shown in Figure 3-3. The vector voltmeter gives the field reading and the phase difference with respect to channel A, the signal source phase. The field and phase are later normalized with a certain value obtained for each different feed point and thickness change in the dielectric.

The probe is shown in Figure 3-4 and has a diameter of .053 cm. and a total length of .526 cm. The probe is mounted such that it can be screwed in and out of the ground plane into the cavity of the antenna.

3-3 Model Results

3-3a Impedance

The model impedance was measured using three varying thicknesses of dielectric. The first step was to calculate the electrical thickness, kd (wavelengths in the dielectric), for the various thicknesses in order to make comparisons with those in Table 3.[13] These are the values of kd for actual printed circuit antennas previously investigated experimentally.

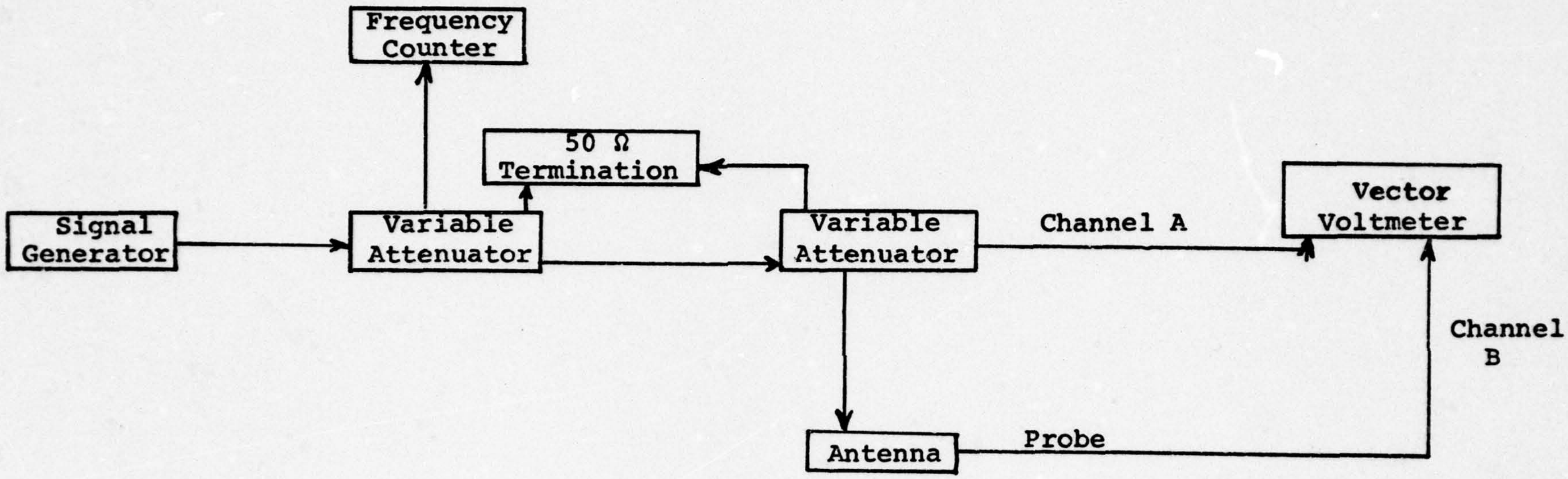


Figure 3-3

Field Measurement Block Diagram

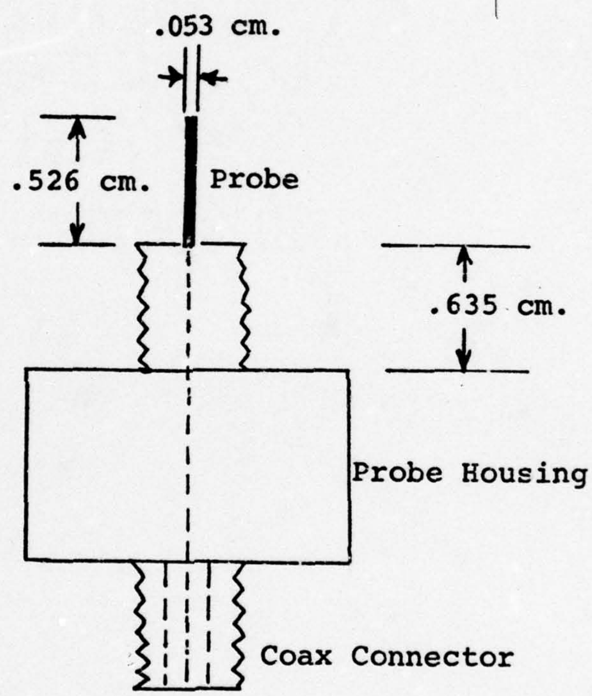


Figure 3-4

Field Probe

TABLE 3[13]

Design Parameters for Circular Printed Circuit Antennas

d(mm)	d(inch)	kd
1.52	.0599	.148
.75	.0296	.073
.36	.0143	.035
.13	.0053	.013

f_o = 2.96 GHZ, ε_r = 2.56, ka = 1.84, a = 1.89 cm.

Table 4 and Table 5 show kd for both the 600 MHZ and 1 GHZ model circular disc.

TABLE 4

Design Parameter for Circular Disc Antenna (Model)

d(mm)	d(inch)	kd
12.7	.50	.161
9.53	.375	.111
6.35	.25	.080

f_o = 600 MHZ, ε_r = 1.014, ka = 1.84, a = 14.54 cm.

TABLE 5

Design Parameters for Circular Disc Antenna (Model)

d(mm)	d(inch)	kd
12.7	.50	.268
9.53	.375	.185
6.35	.25	.134

f_o = 1 GHZ, ε_r = 1.014, ka = 1.84, a = 8.729 cm.

Comparing the tables, it can be seen that the kd values for the 600 MHZ model fall among and slightly above the kd values of the printed circuit antennas. From this one would expect to find some differences in results but not an appreciable amount.

In the impedance measurement taken it was necessary to interpolate between some points in order to find values of extrema as well as to help determine the exact shape of the curves. These interpolations were done by converting the impedance (Z_L) of the points to admittances (Y_L) and finding the conductance (G_L) and susceptance (B_L). This is done because these curves are very nearly linear over narrow frequency bands near resonance. Once the conductance and susceptance of the new point are found from the linear approximation, they are then converted back to resistance and reactance at that frequency. The data points from these interpolations will appear as triangles (Δ) on all graphs.

The first model investigated was the 600 MHZ circular

disc. Figures 3-5 and 3-6 illustrate that the resonant frequency is a direct function of the thickness of the dielectric. The thinner the dielectric the higher the resonant frequency. Although Figures 3-5 and 3-6 depict only the edge feed location, others can be compared using Figures 3-7 through 3-12. This is also shown in the data in Appendix III. Figures 3-5 and 3-6 also bear out the results performed earlier by Howell.[4] It can also be observed that the resonant frequency does vary with each change in feed point for each thickness.

The resonant frequency design of 600 MHZ was never achieved. The resonance was always lower than that of the design. In Figures 3-7 and 3-8 for the .635 cm. dielectric the resonant frequency varied from 548 MHZ to 552.5 MHZ for a 8.33% average below the design frequency. The .953 cm. dielectric varied from 536 MHZ to 541 MHZ for an average of 10.25% below design. This is seen in Figures 3-9 and 3-10. Figures 3-11 and 3-12 show the 1.27 cm. dielectric varying from 525 MHZ to 535 MHZ for an average of 11.67% below the design resonance.

All of the figures are for an ungrounded center, but the data for the grounded center disc shows no noticeable change in the resonance positions. These data points are found in Appendix IV and can be compared with that in Appendix III.

For the case of the 600 MHZ circular disc antenna it can be seen in Figures 3-7 through 3-12 that the antenna did

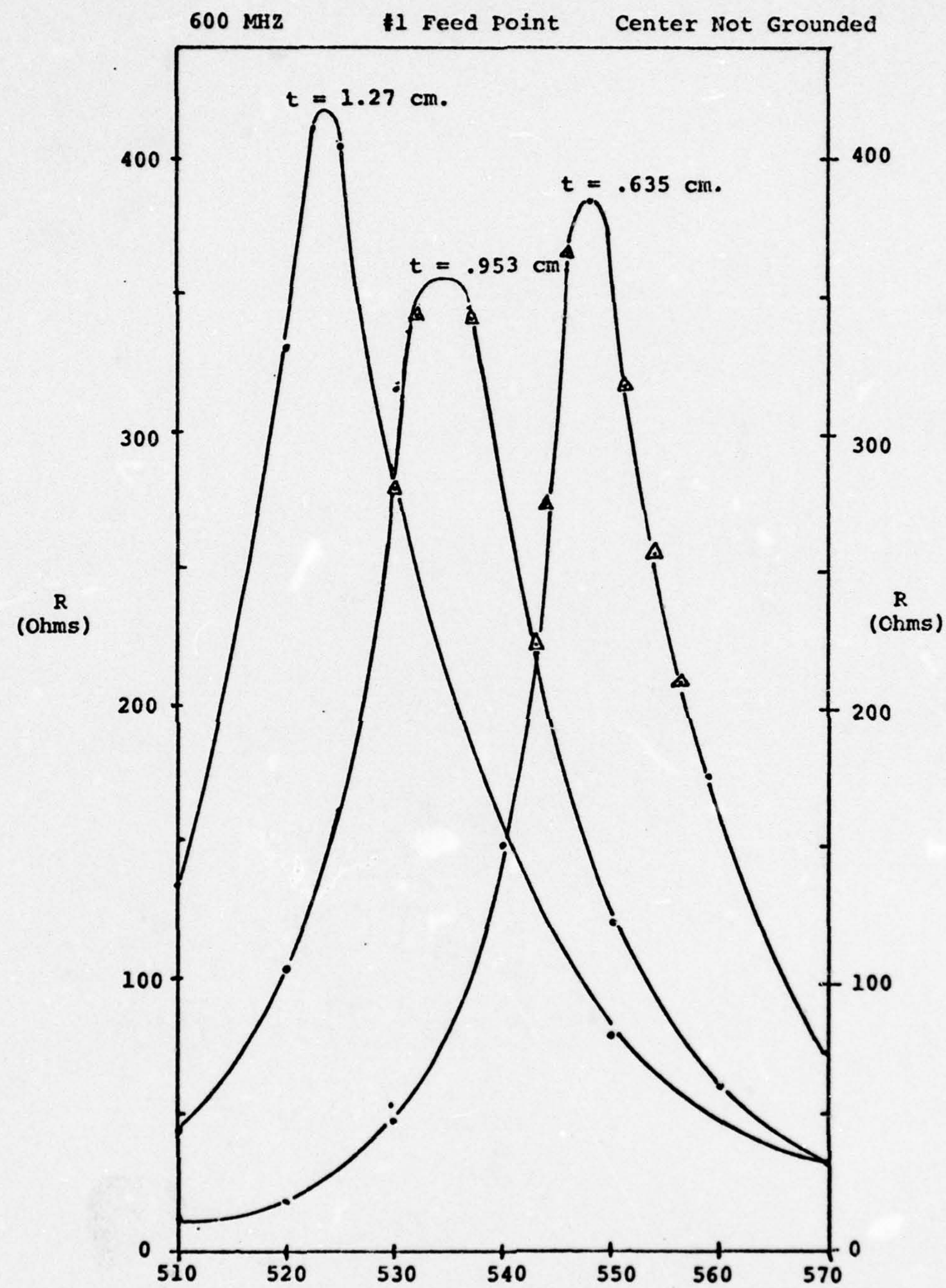


Figure 3-5

Resistance Vs. Frequency

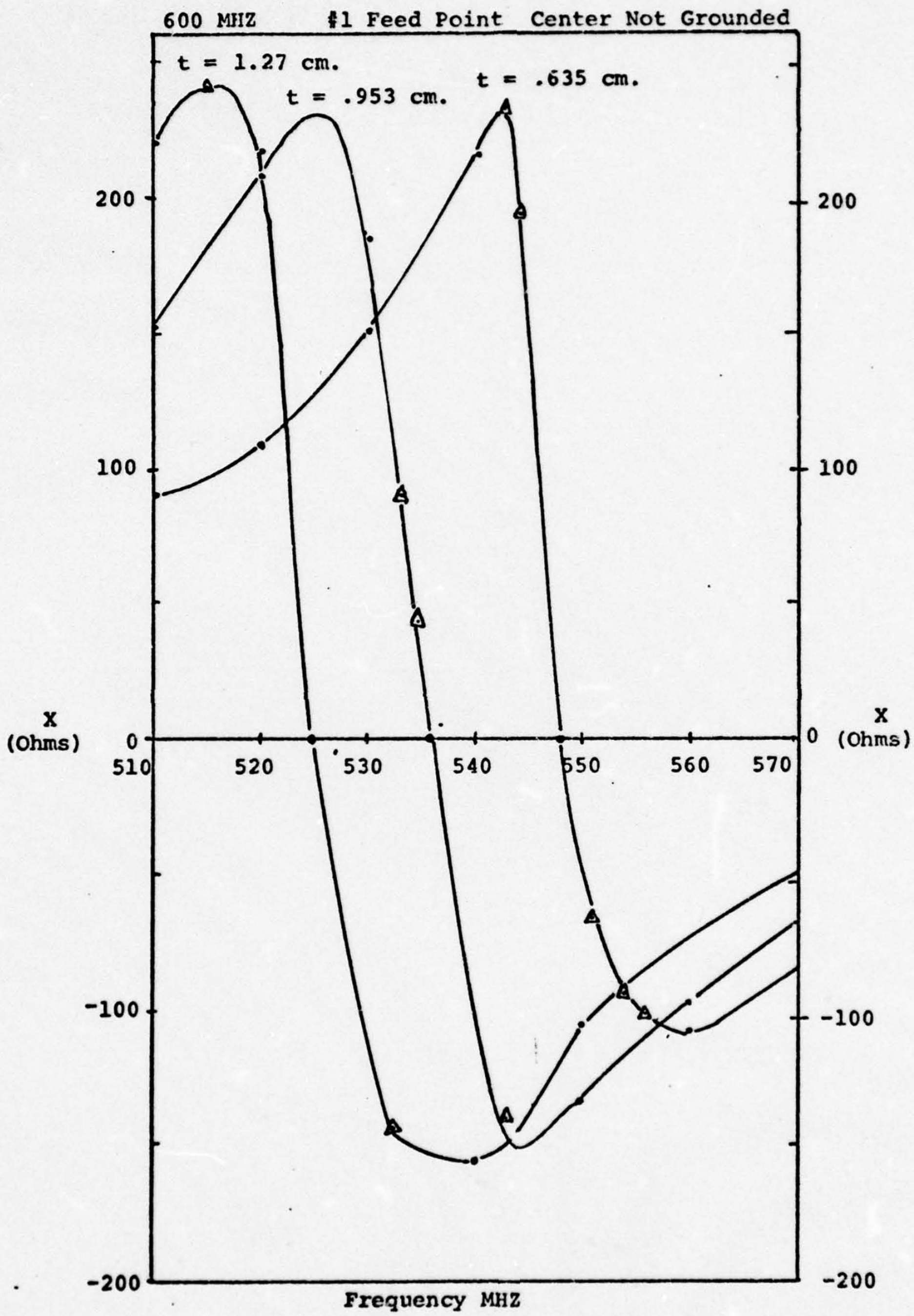


Figure 3-6

Reactance Vs. Frequency

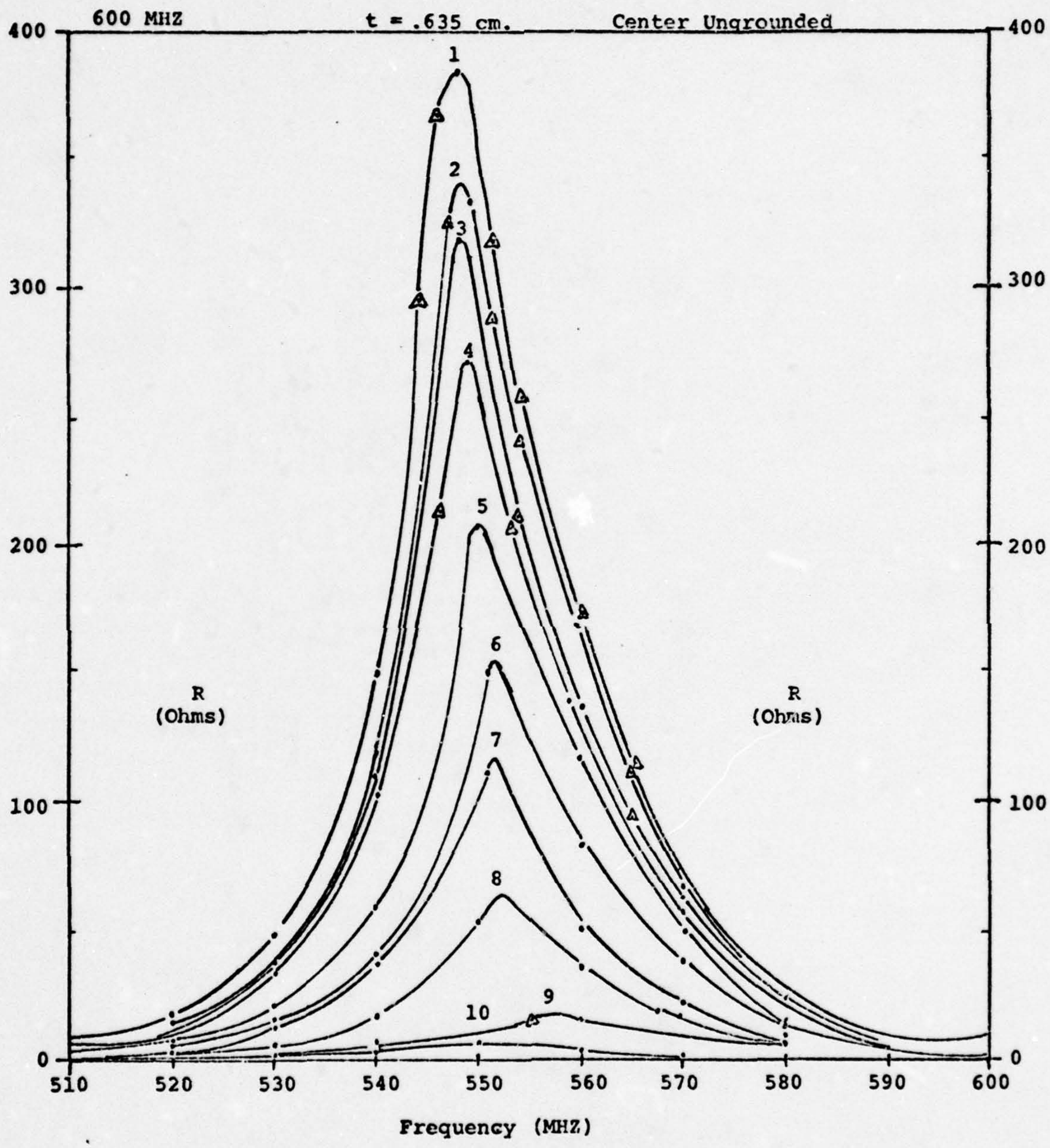


Figure 3-7

Resistance Vs. Frequency

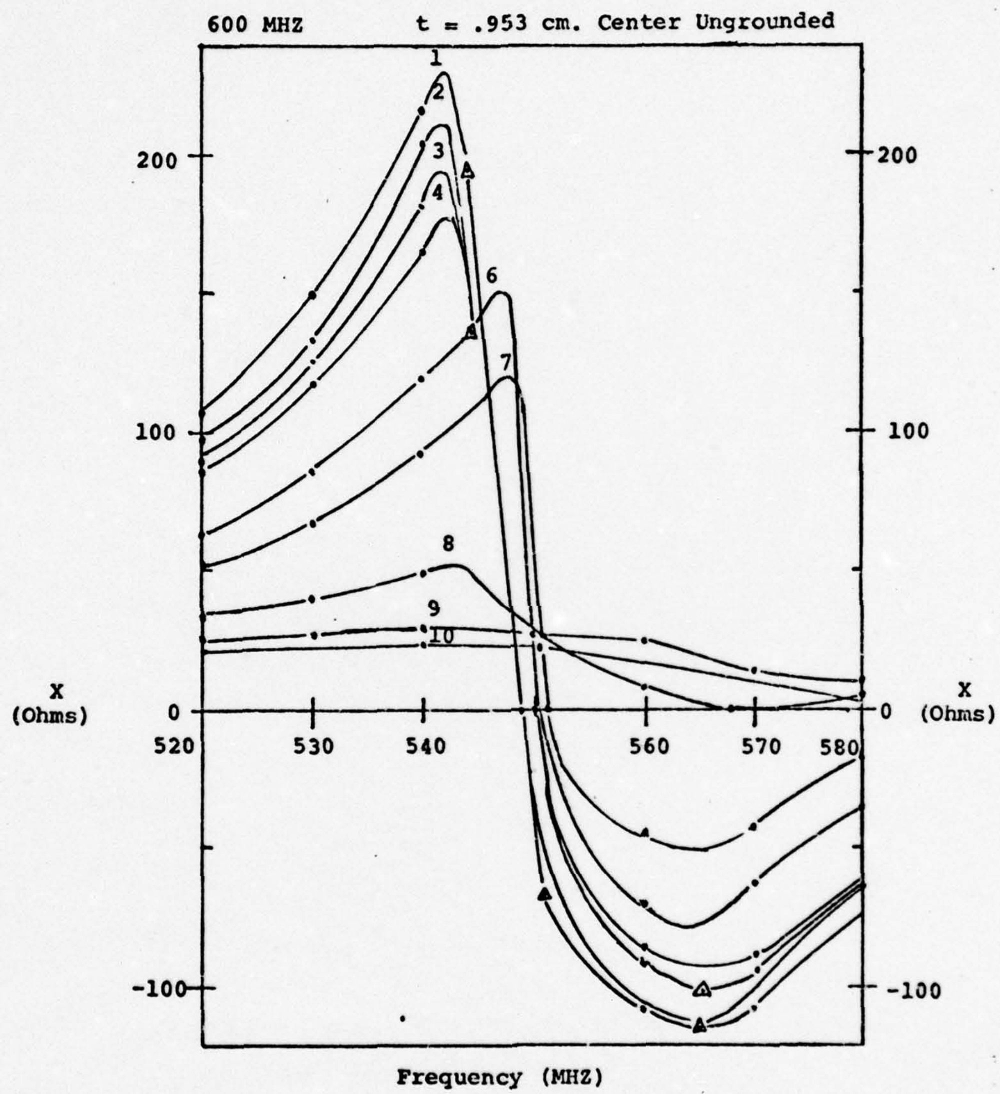


Figure 3-8

Reactance Vs. Frequency

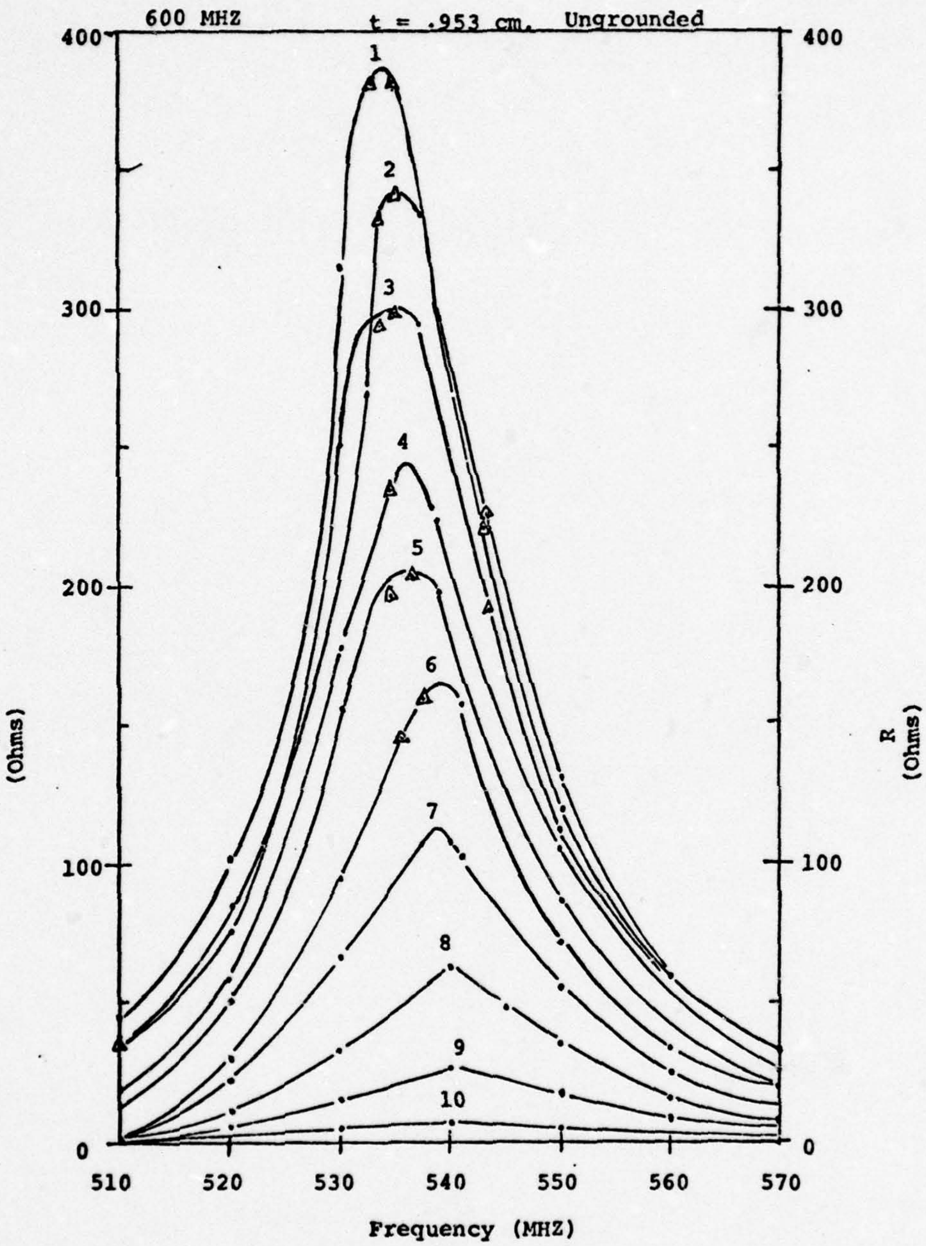


Figure 3-9

Resistance Vs. Frequency

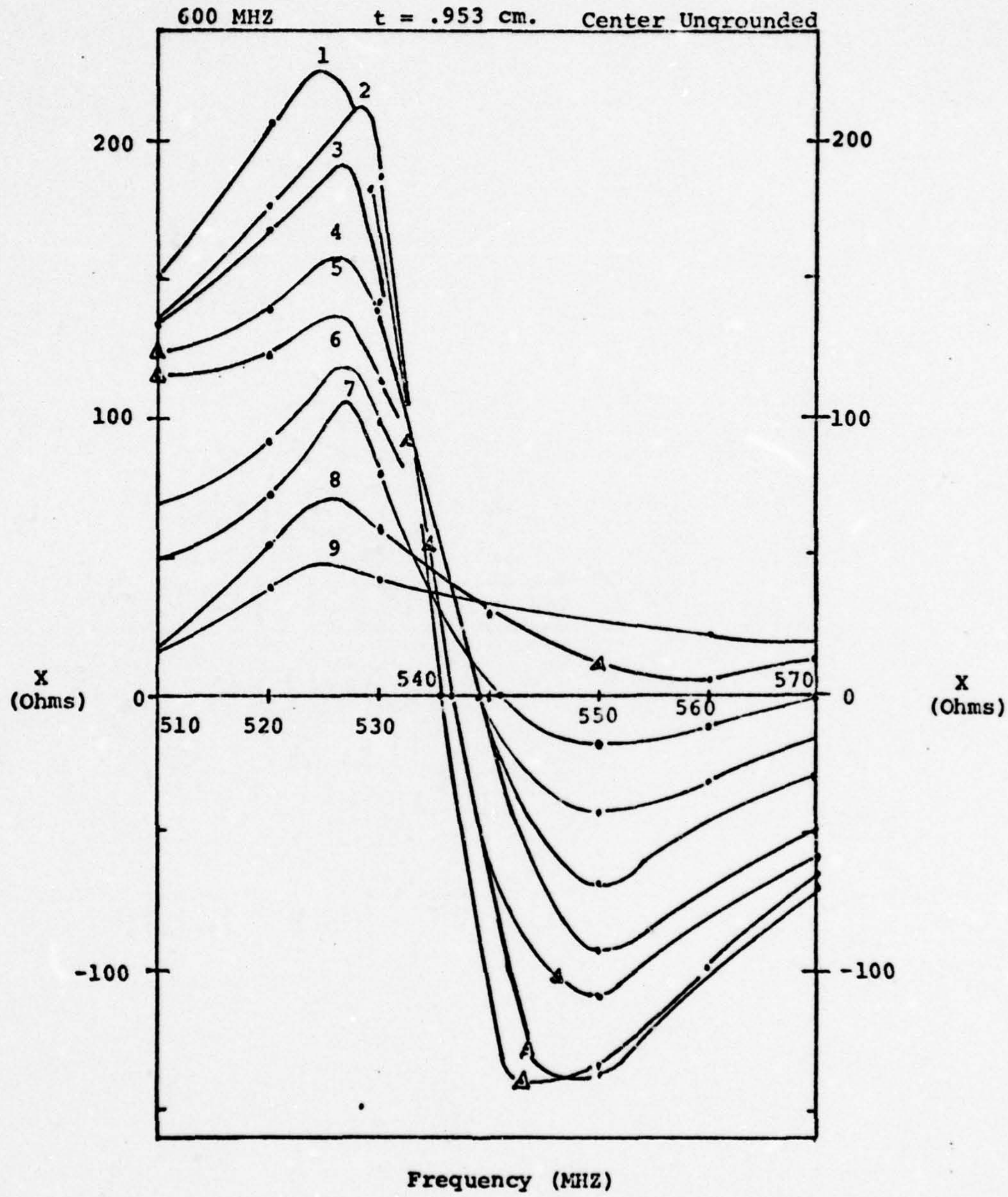


Figure 3-10

Reactance Vs. Frequency

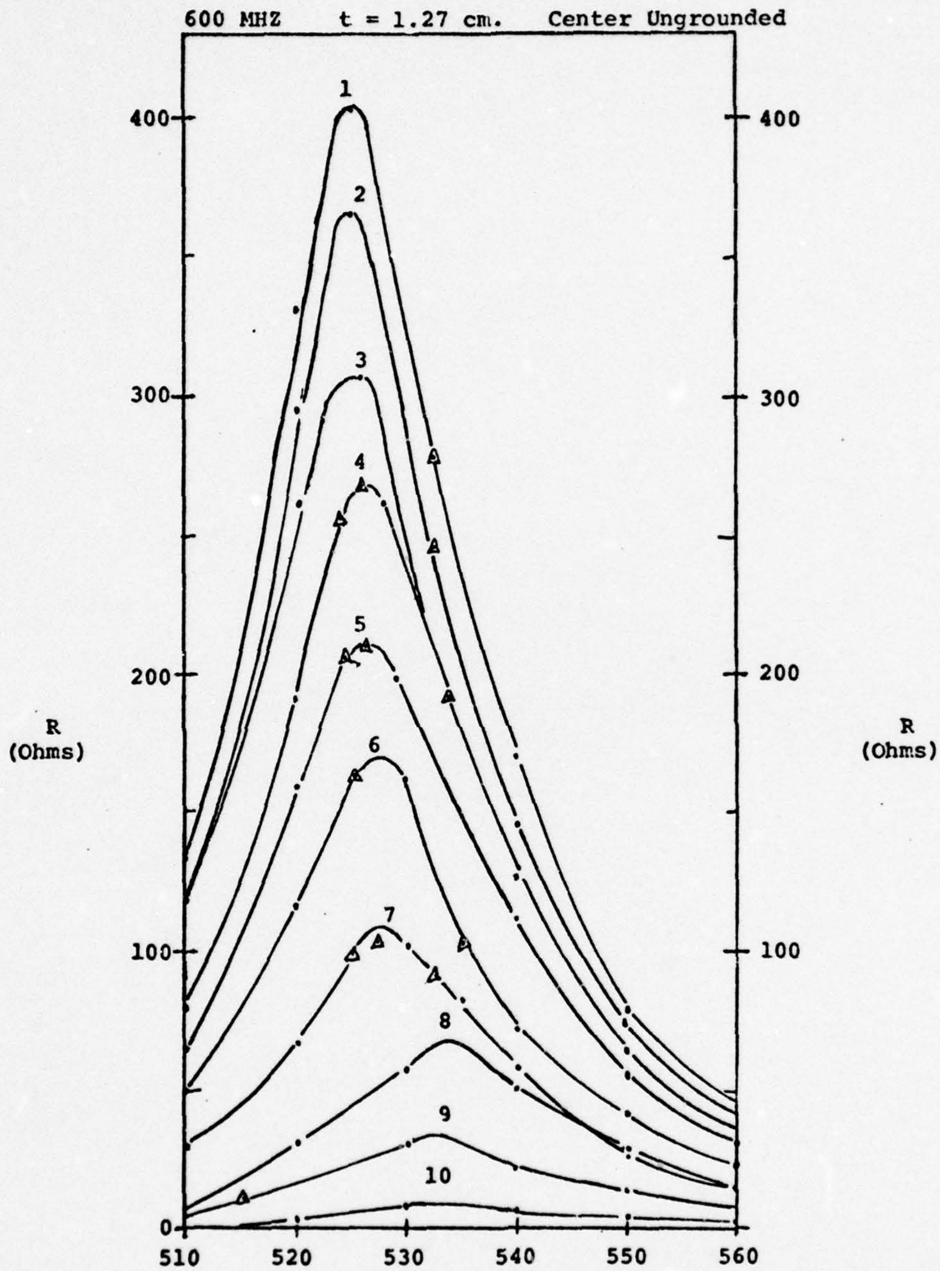


Figure 3-11

Resistance Vs. Frequency

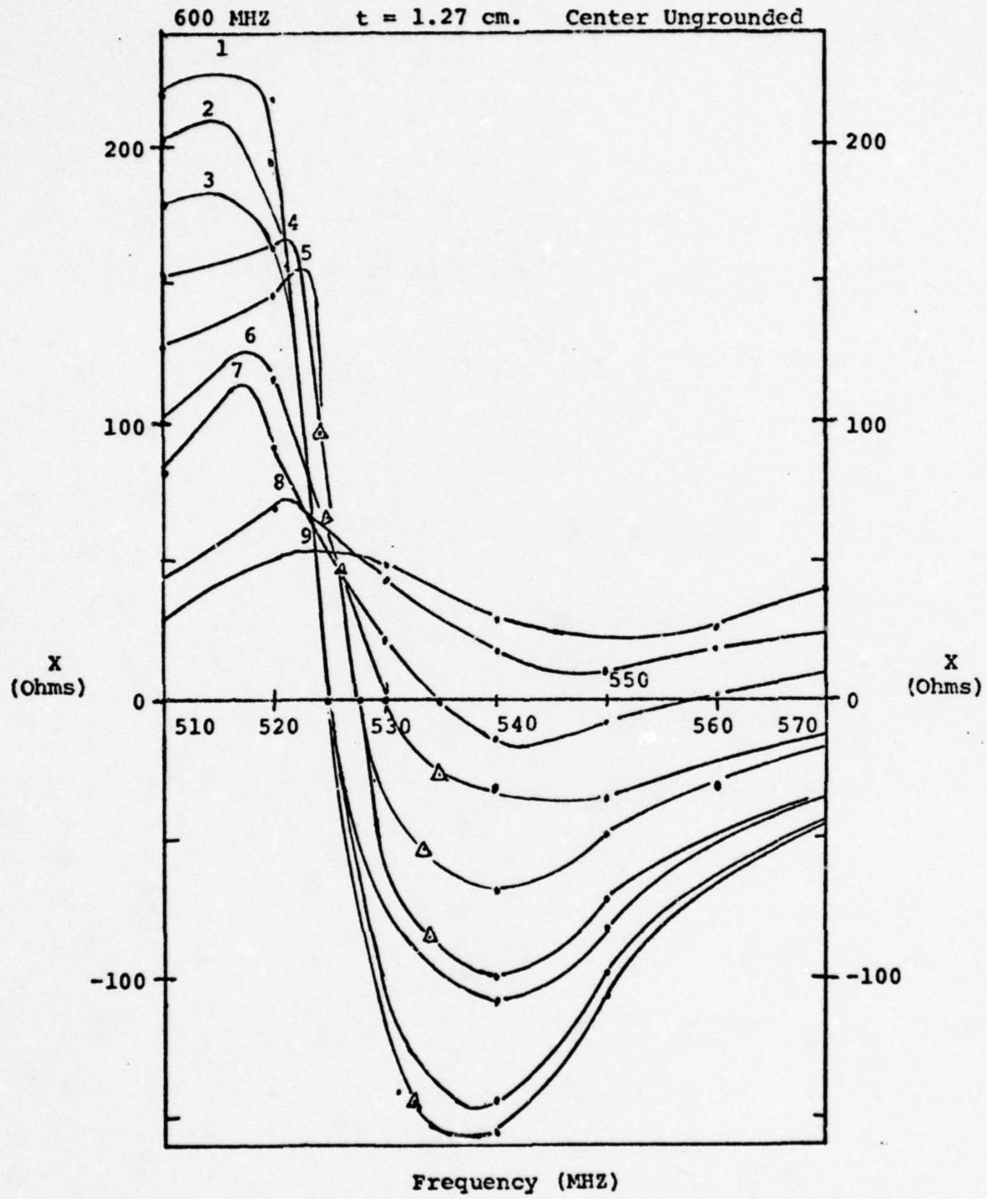


Figure 3-12

Reactance Vs. Frequency

not have a true resonant point once the feed point was moved to point 8 or closer to the center of the disc. Once the radius exceeded or equalled 5.76 cm. then there was resonance. This is not to say that resonance did not occur, but that the impedance still had a finite reactance value for all frequencies until the feed was moved to a point greater than 5.76 cm. from the center. Then a proper impedance match could be made. This occurred at 39.6% of the radius from the center.

The 1 GHZ circular disc antenna was measured next. Again as with the 600 MHZ disc the 1 GHZ disc resonant frequency was found to increase as the dielectric thickness decreases. This is illustrated in Figures 3-13 and 3-14. Figures 3-15 through 3-20 again show the decrease in magnitude with change in feed point location and also show the variation of the resonant frequency as the feed point is changed for each thickness. For the 1 GHZ design the resonance is below the design value for all thicknesses. For the .635 cm. thick dielectric, the resonance varies from 888 MHZ to 894 MHZ, for an average of 10.9% below design. The .953 cm. dielectric varies from 851 MHZ to 870 MHZ, for an average of 13.95% below design. The 1.27 cm. dielectric varies from 834 MHZ to 850 MHZ, for an average of 15.8% below design resonance. Again certain feed points are noted not to have resonant points. This occurs at feed point 7 and closer to the center. When the radius exceeds 3.44 cm., resonance again takes place as it did for the 600 MHZ disc. Again this point is located approximately 39% of the radius away

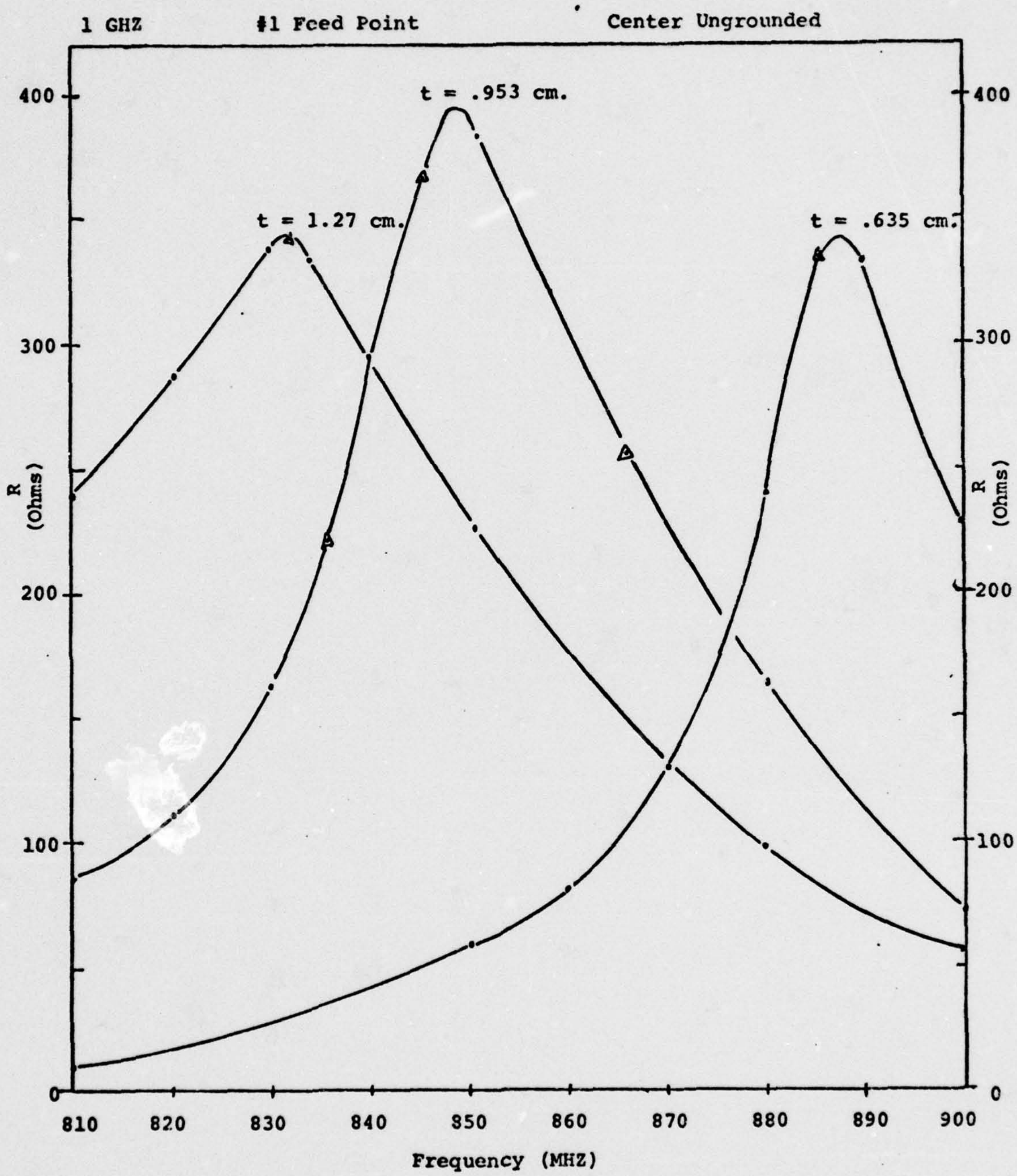


Figure 3-13
Resistance Vs. Frequency

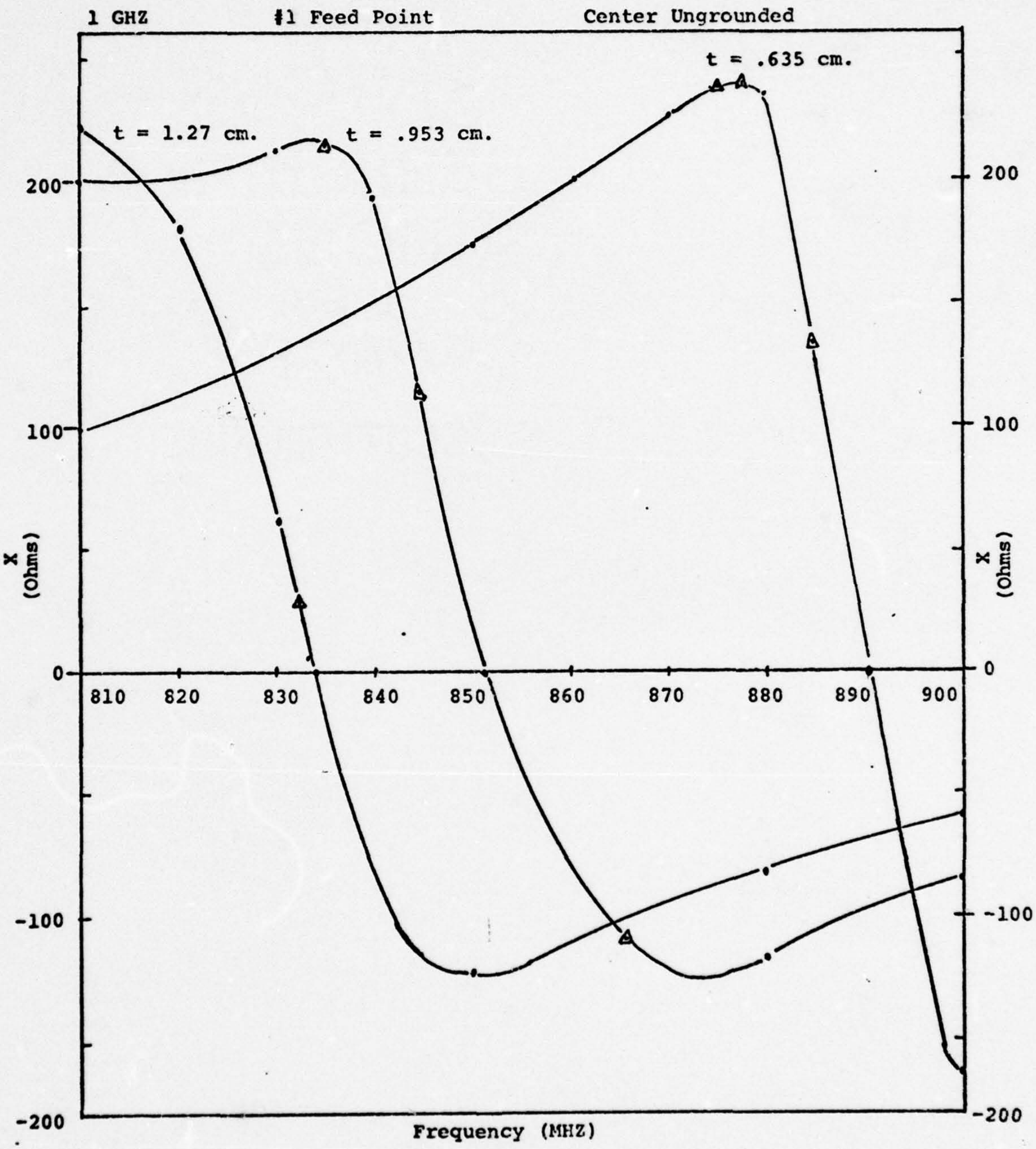


Figure 3-14

Reactance Vs. Frequency

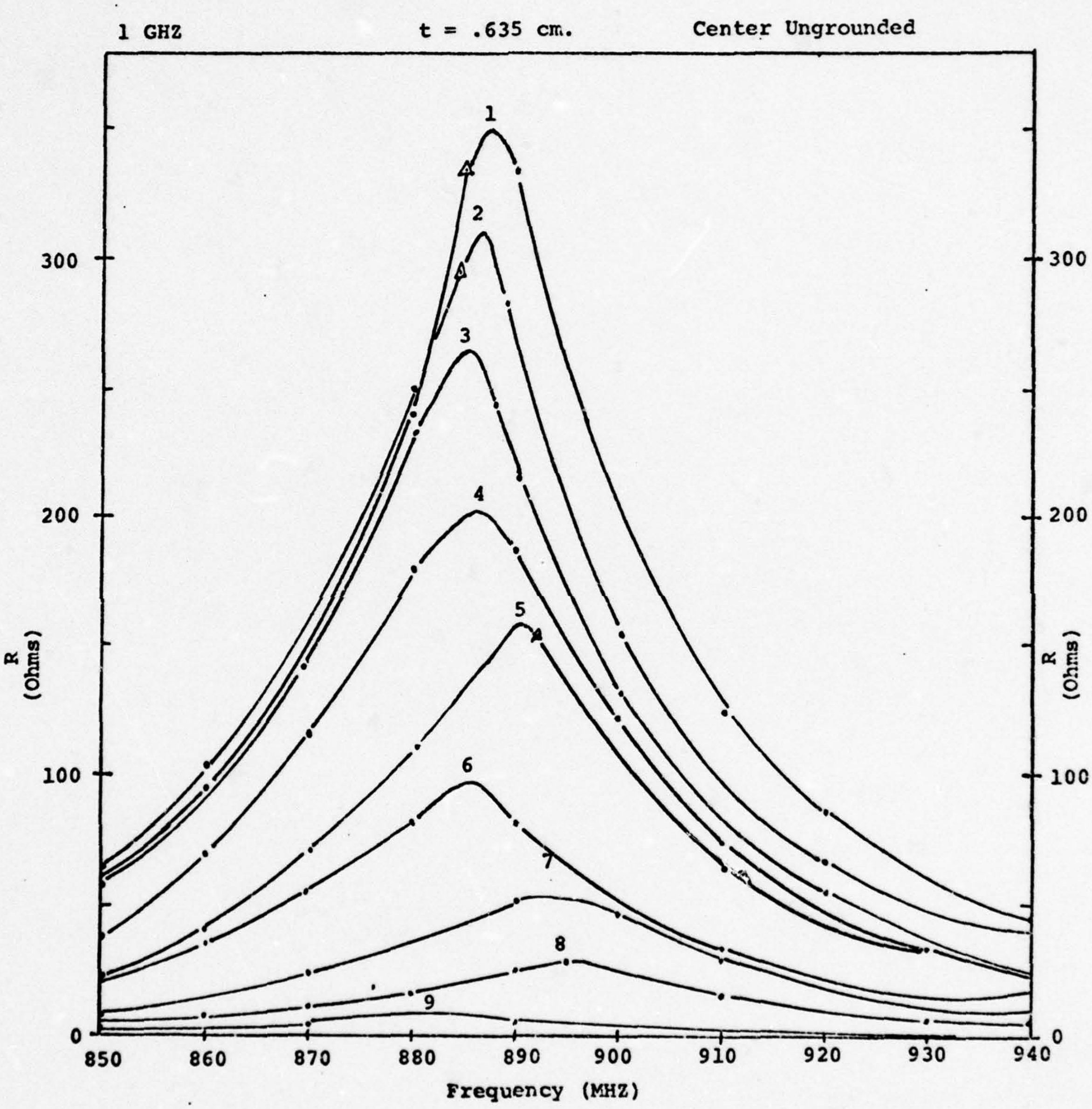


Figure 3-15

Resistance Vs. Frequency

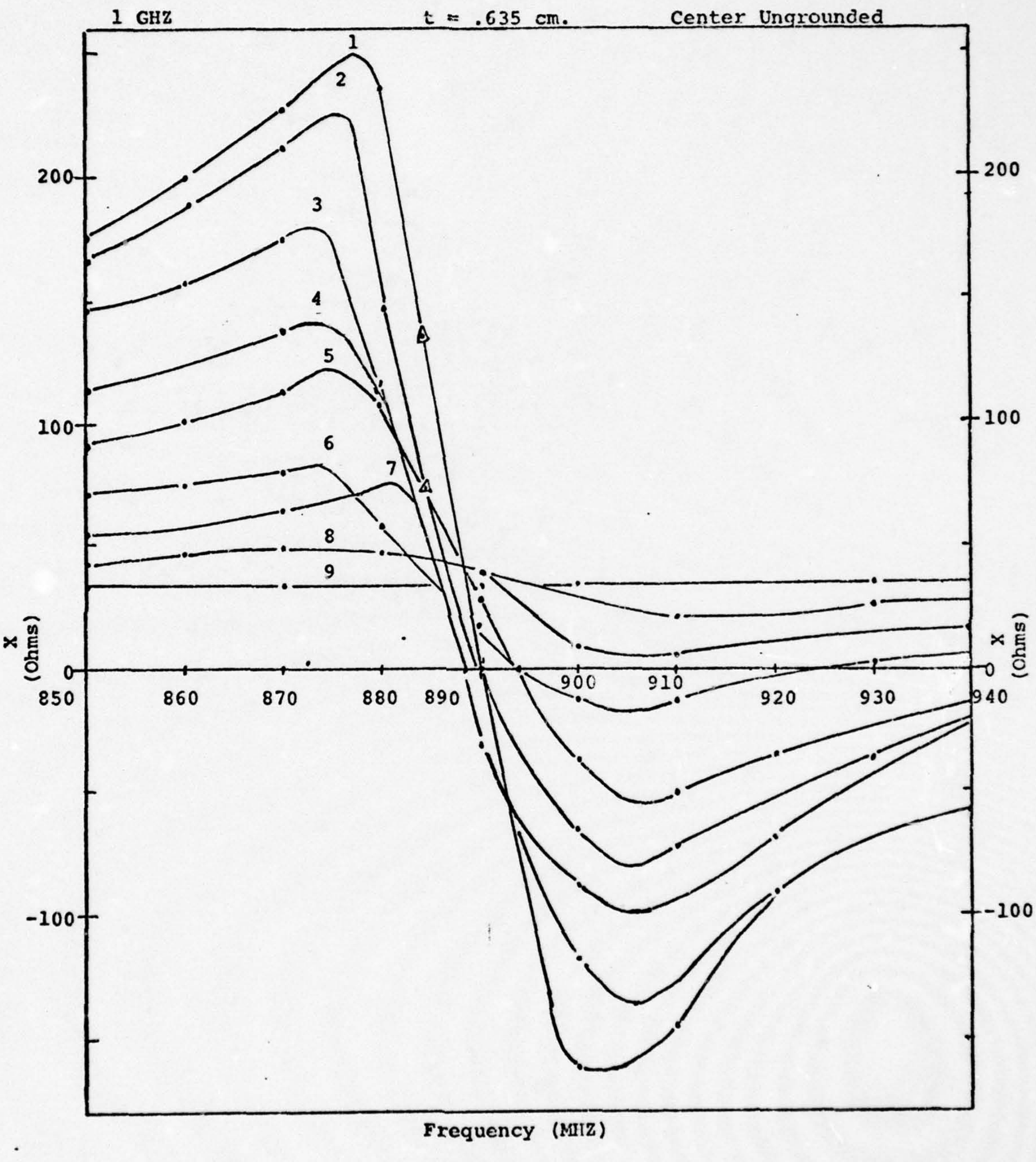


Figure 3-16

Reactance Vs. Frequency

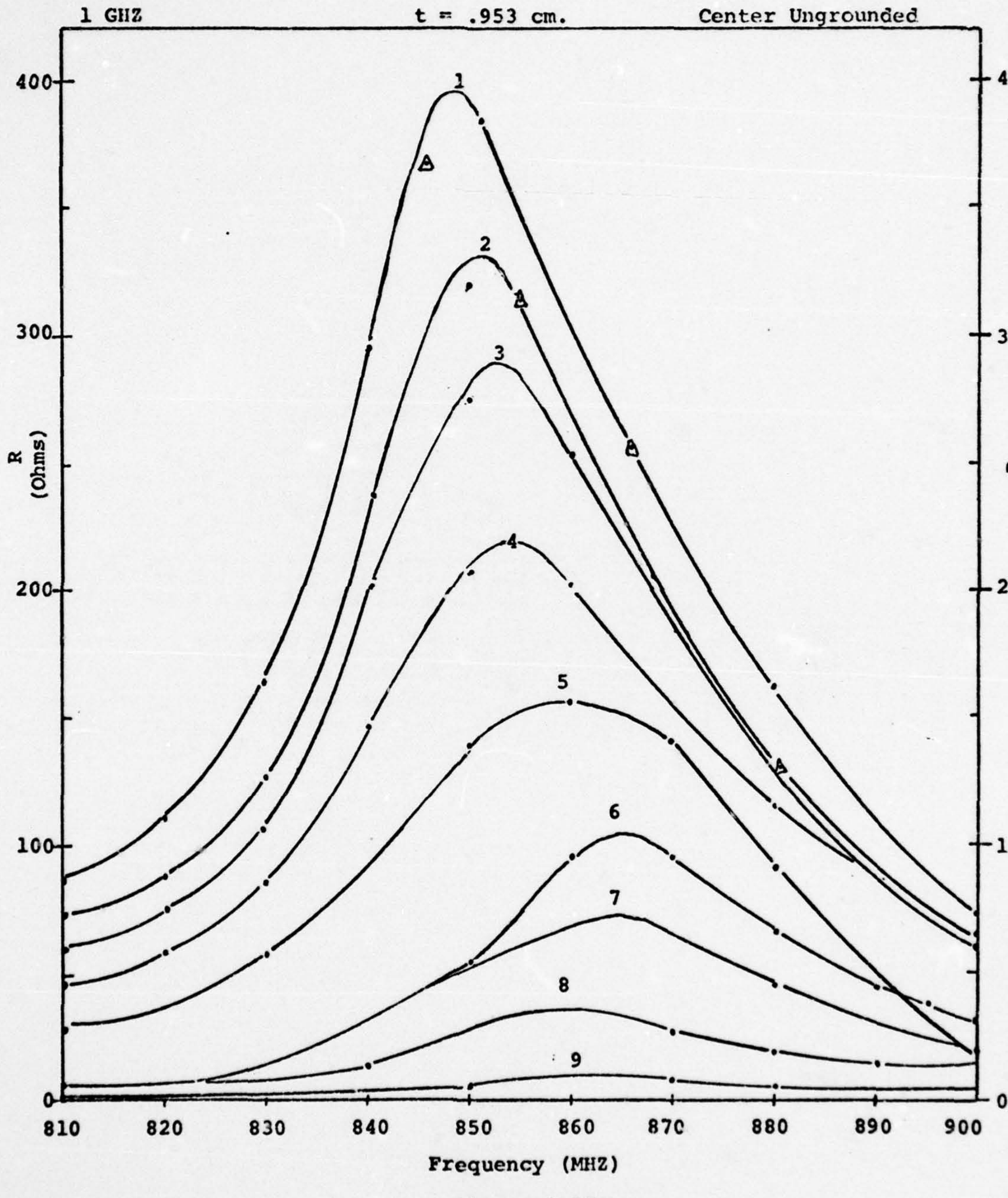


Figure 3-17

Resistance Vs. Frequency

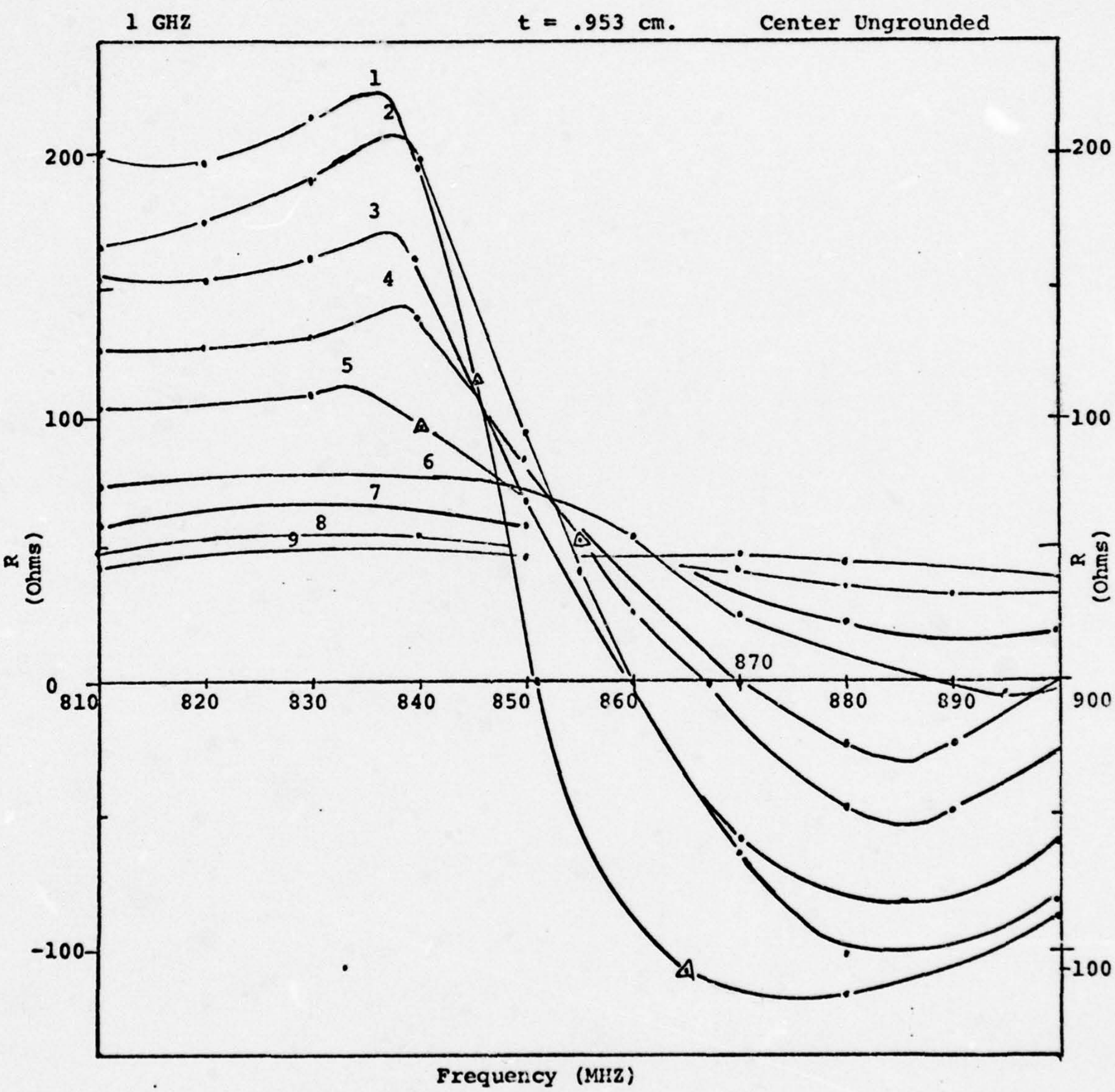


Figure 3-18

Reactance Vs. Frequency

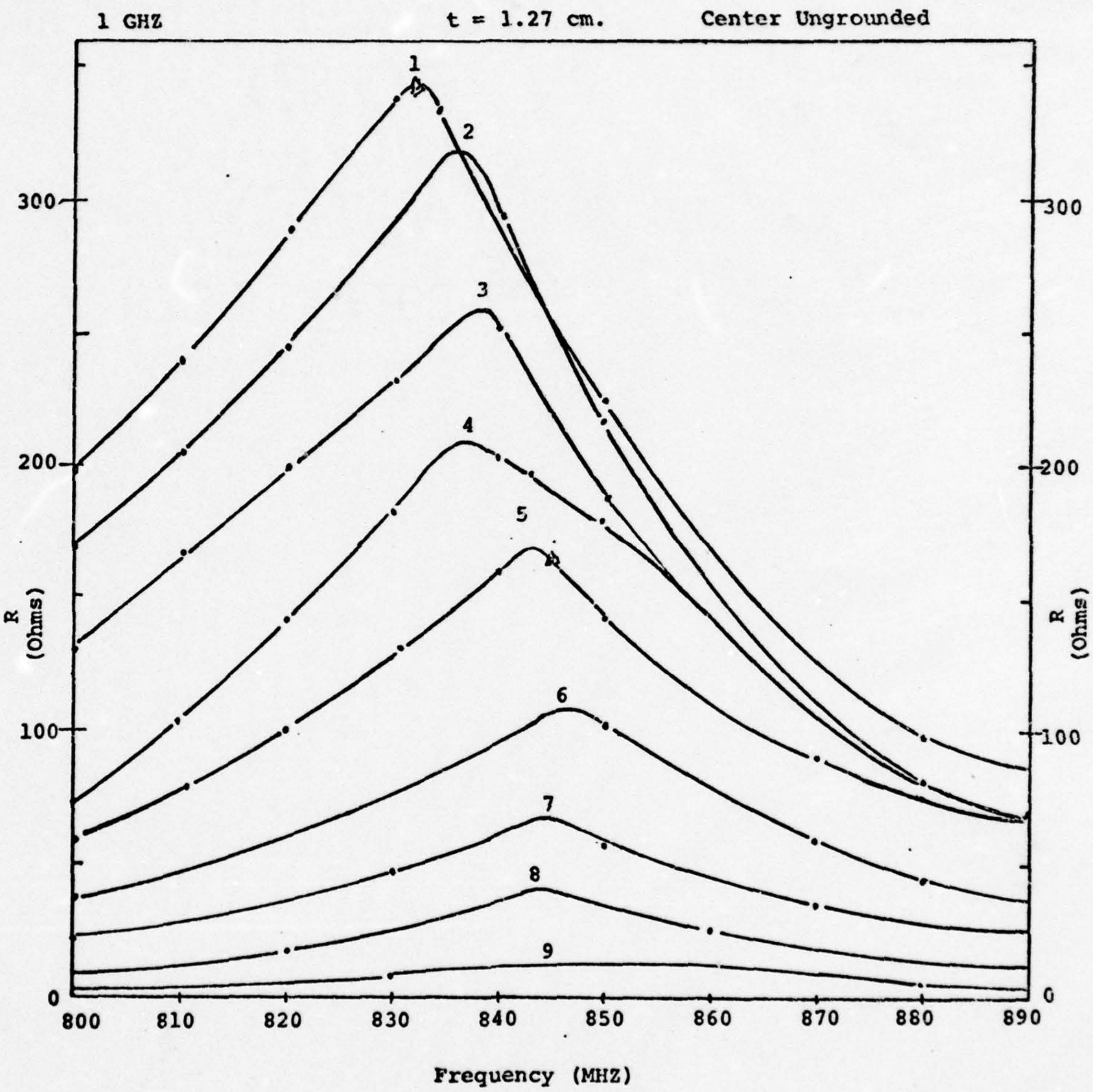
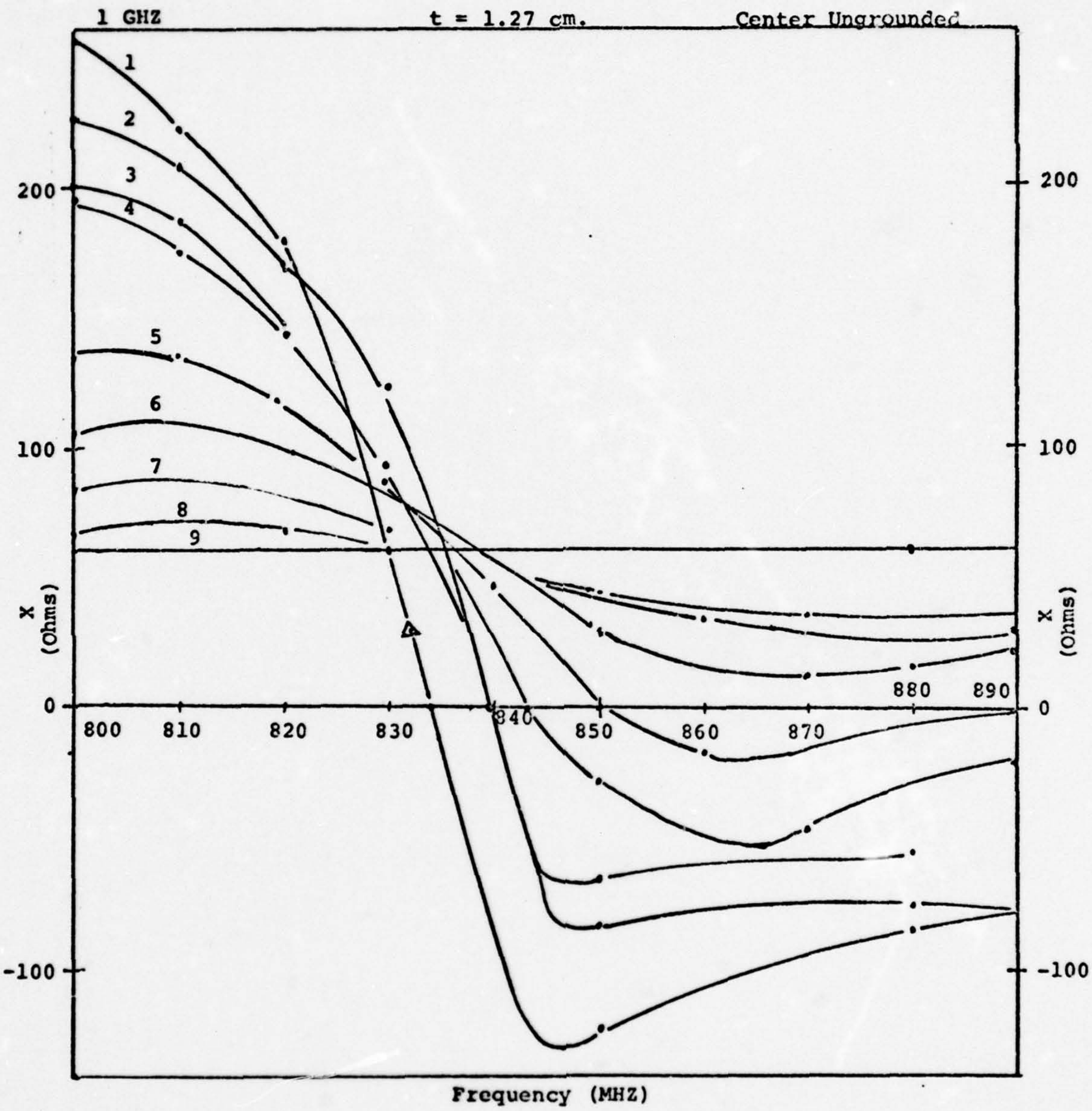


Figure 3-19

Resistance Vs. Frequency



Frequency (MHZ)

Reactance Vs. Frequency

from the center. The data for the 1 GHZ grounded disc are given in Appendix VI and may be compared with the data in Appendix V which show virtually no change in resonance frequencies.

3-3b Field Measurements

The field measurements were taken using the probe and vector voltmeter described earlier in the chapter. Both the 600 MHZ and 1 GHZ disc radiators were used. The electric field inside the structure was measured and then plotted in Figures 3-21 to 3-24. The theoretical value of the electric field (valid only for the edge fed case) is given by:

$$E_Z = E_o J_1 (kr) \cos \phi \tag{11}$$

where J_1 = 1st order Bessel function

$k = \frac{2\pi}{\lambda}$

r = radius of disc

ϕ = azimuthal angle measured from feed point

Figures 3-21 and 3-24 show the electric field measurements as a function of position for various dielectric thicknesses. For both discs, 600 MHZ and 1 GHZ, the phase changes approximately 180 degrees near the minimum of the field magnitude. Figures 25 through 28 for different feed point locations tend to show a shift in the minimum of the field. This shift is more toward centering the field on the disc, with the minimum occurring between the feed point and the

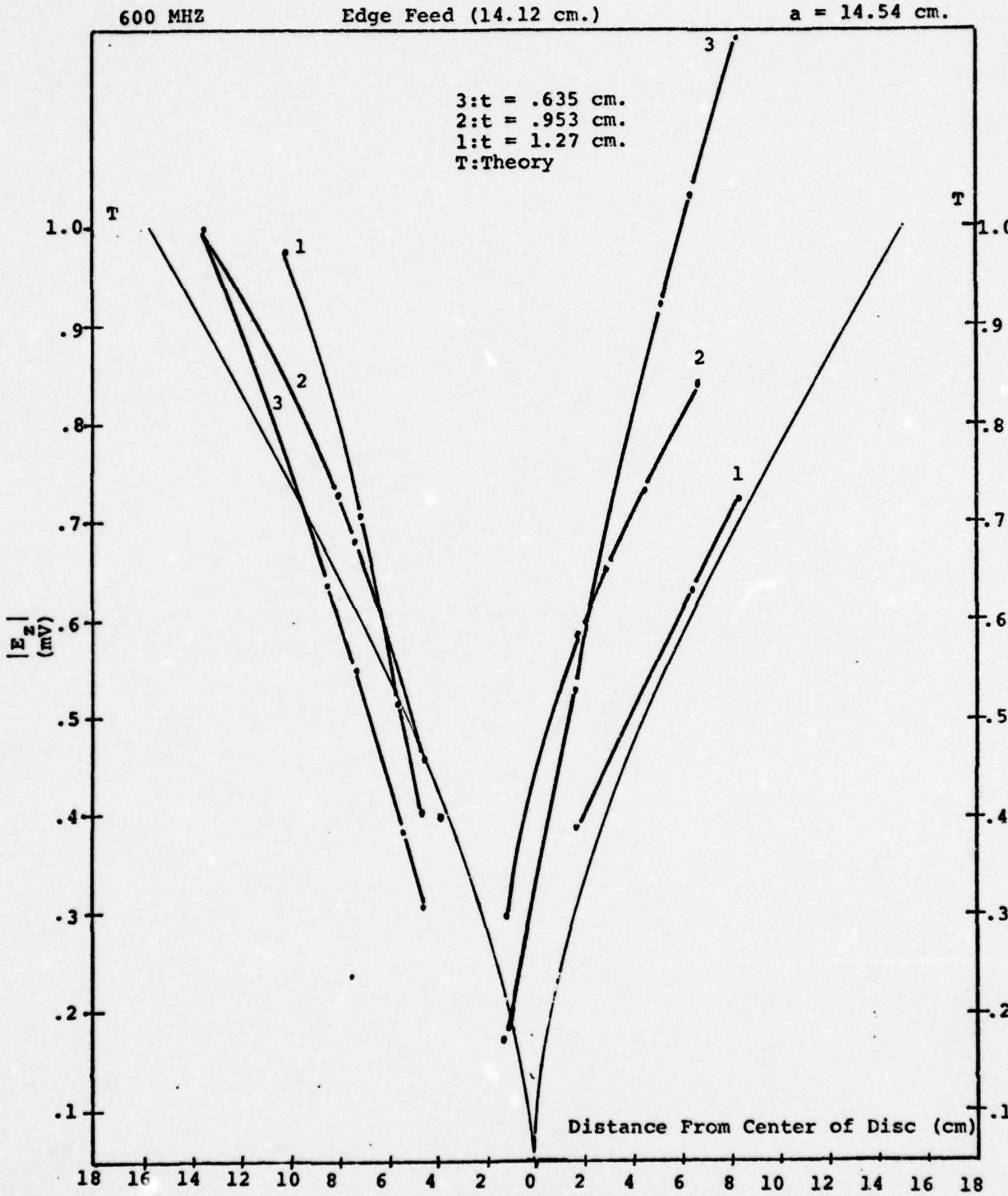


Figure 3-21

Normalized $|E_z|$ Vs. a

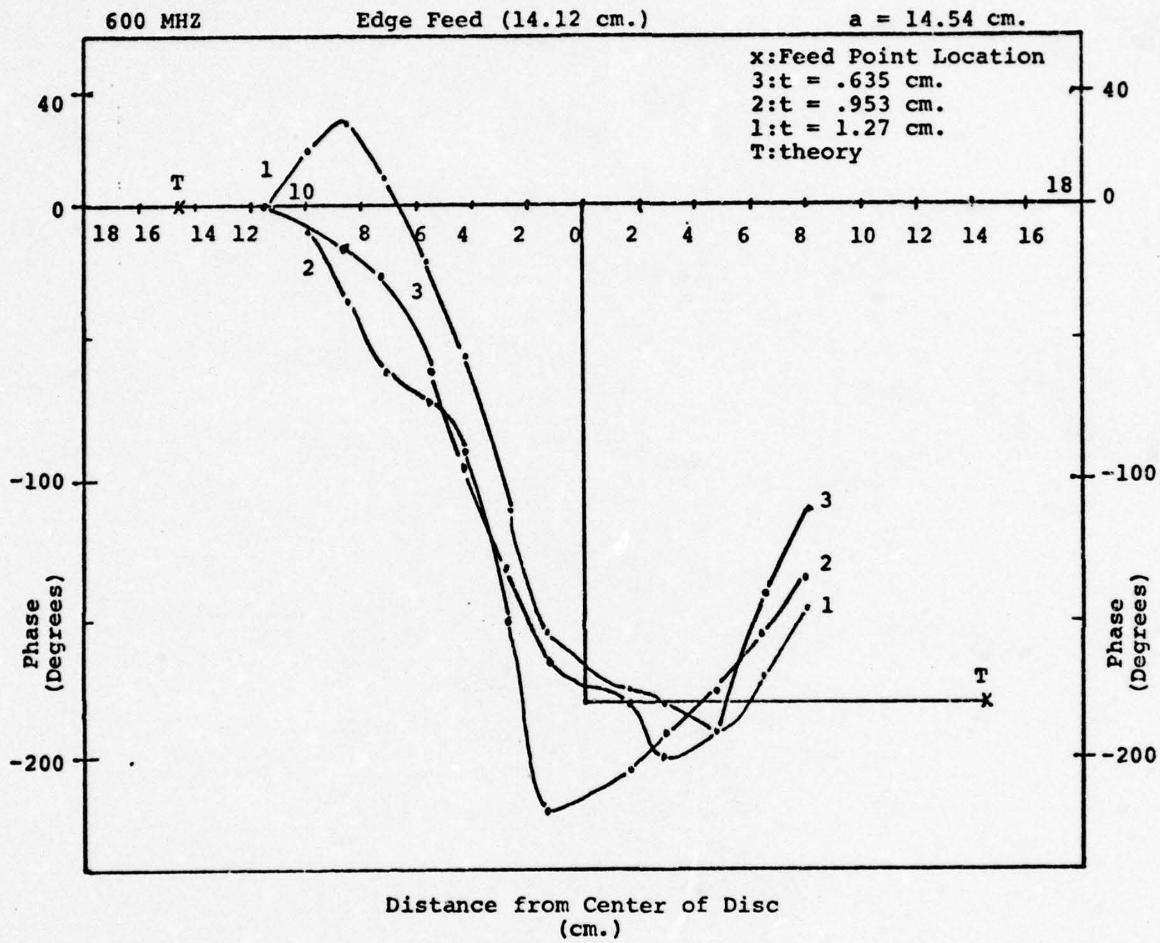
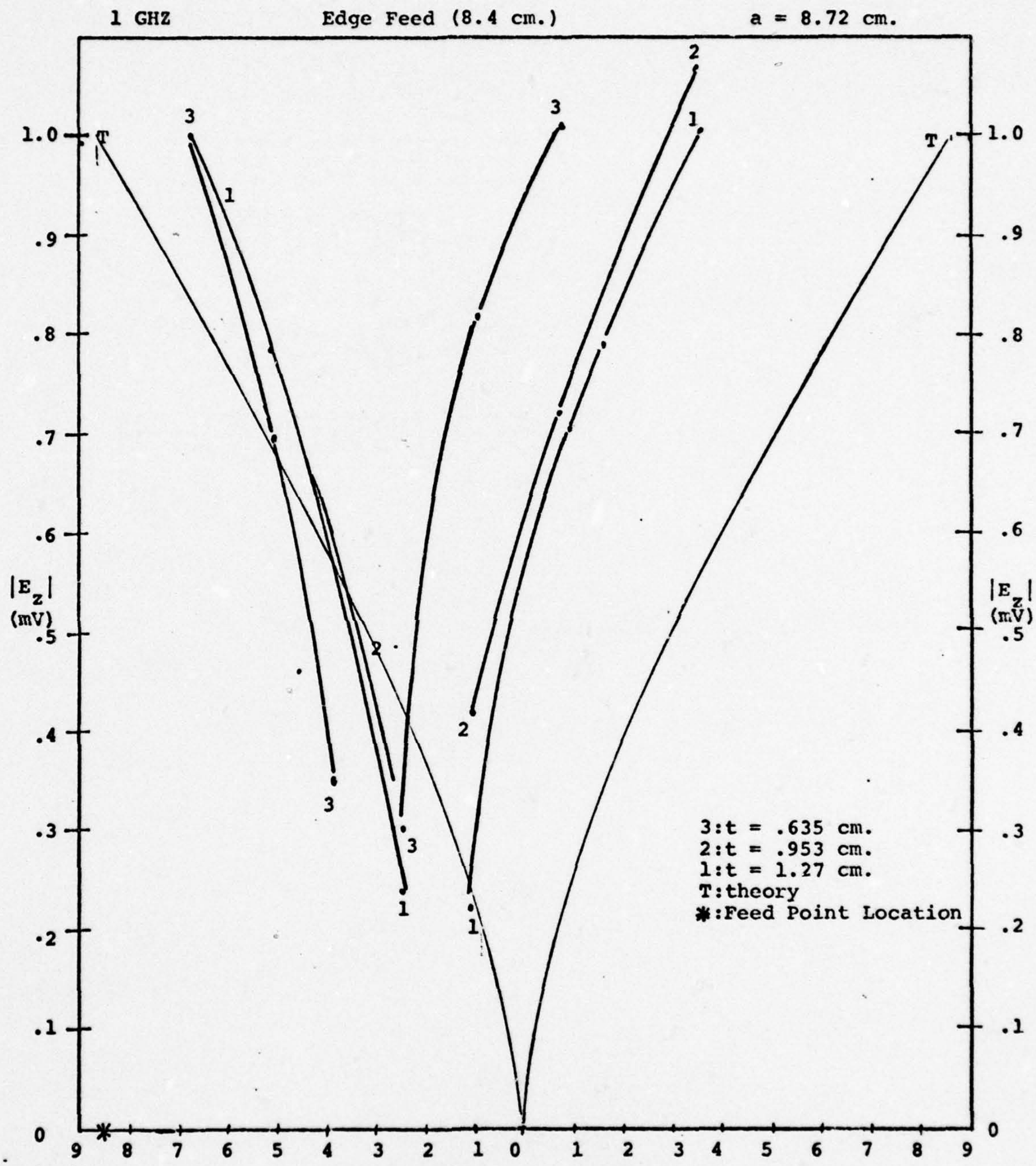


Figure 3-22

Normalized Phase Vs. r



Distance From Center of Disc (cm.)

Figure 3-23
Normalized $|E_z|$ Vs. a

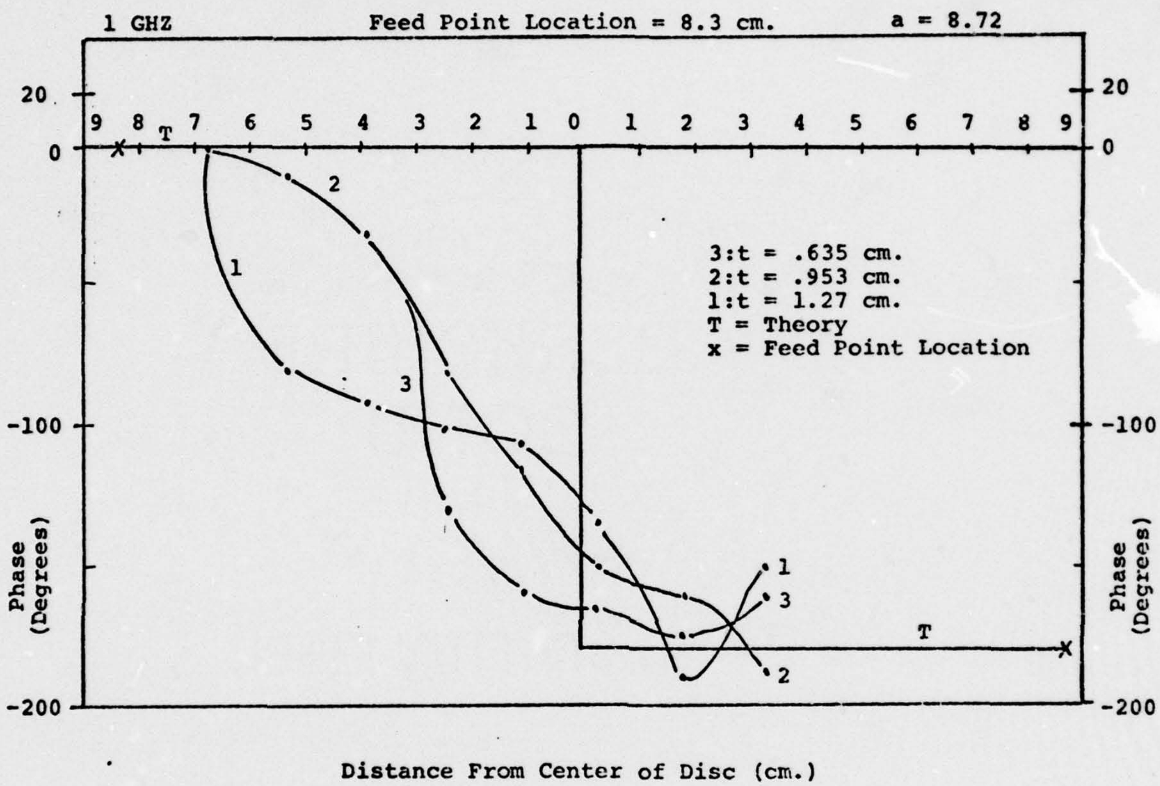


Figure 3-24

Normalized Phase Vs. r

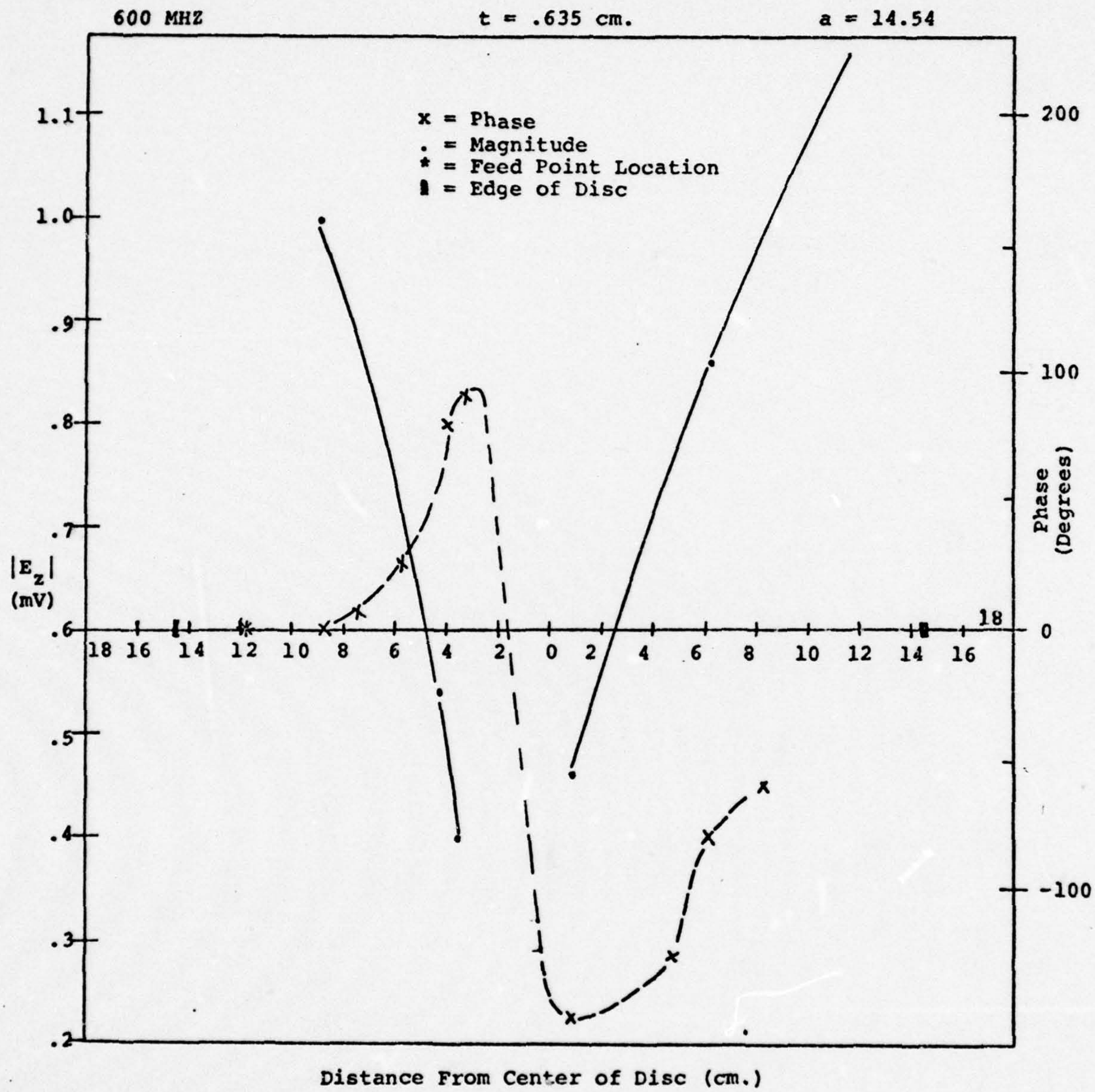
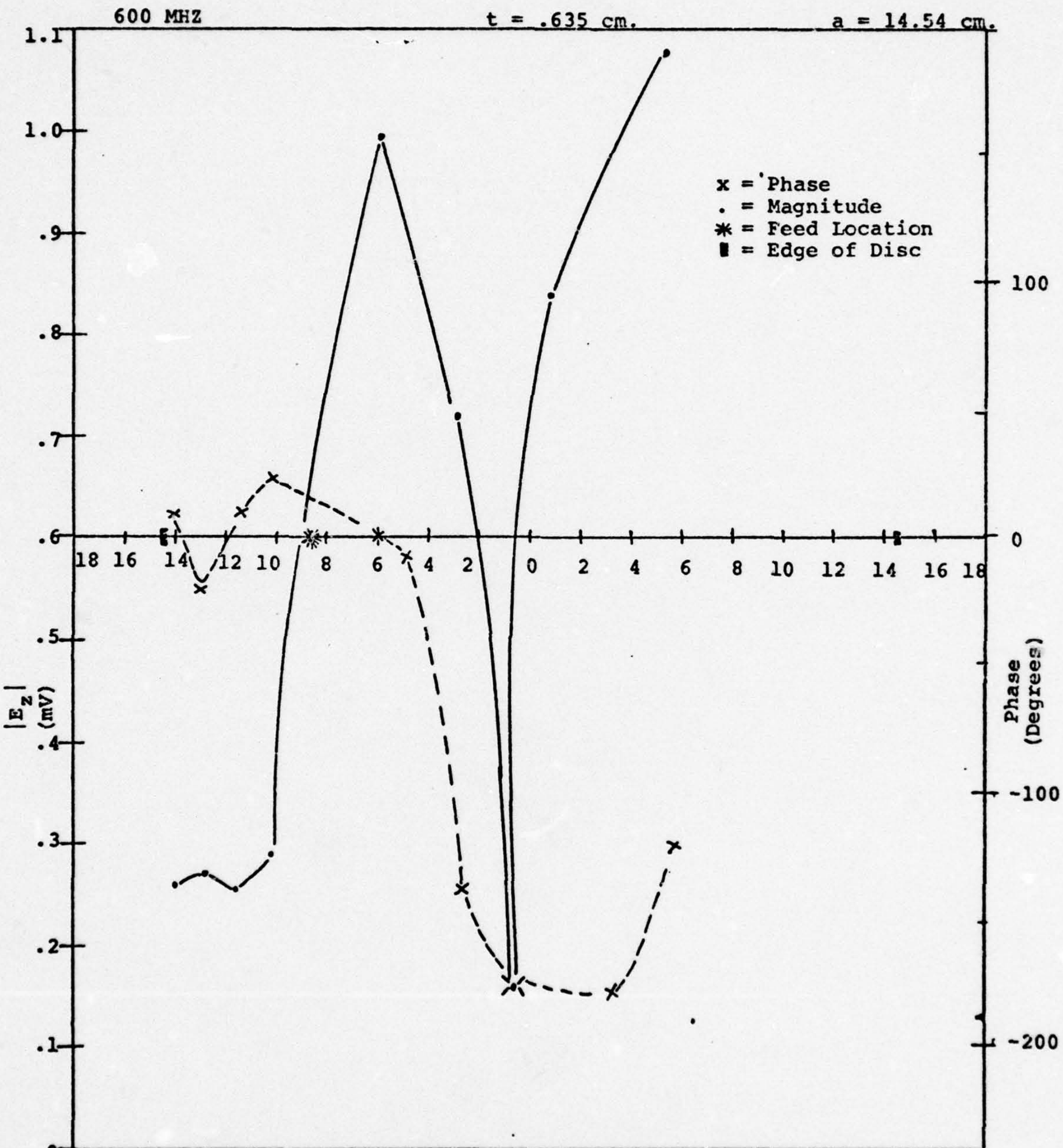


Figure 3-25

Normalized $|E_z|$ and Phase Vs. r



Distance from Center of Disc (cm.)

Figure 3-26

Normalized $|E_z|$ and Phase Vs. r

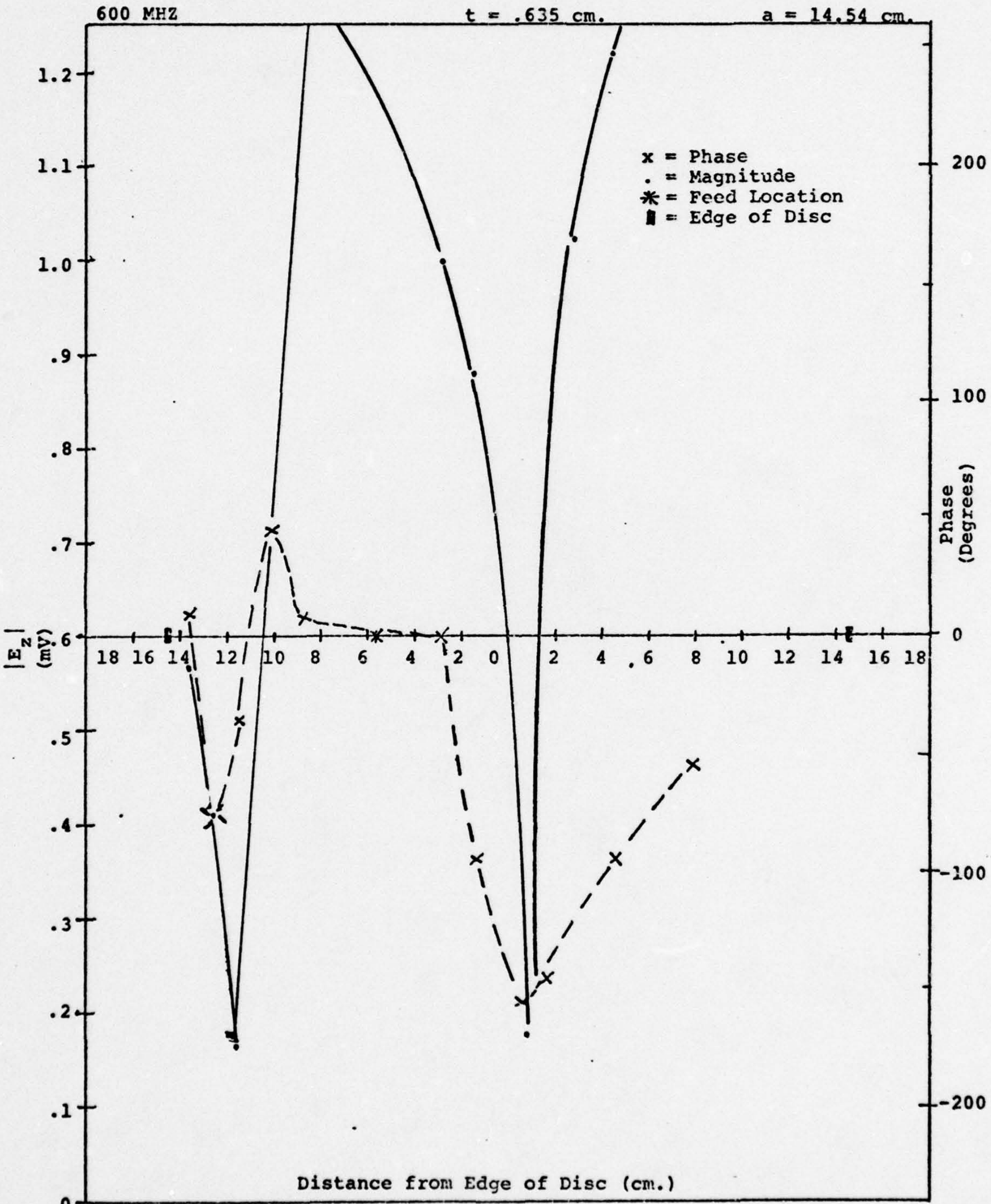


Figure 3-27
Normalized $|E_z|$ and Phase Vs. r

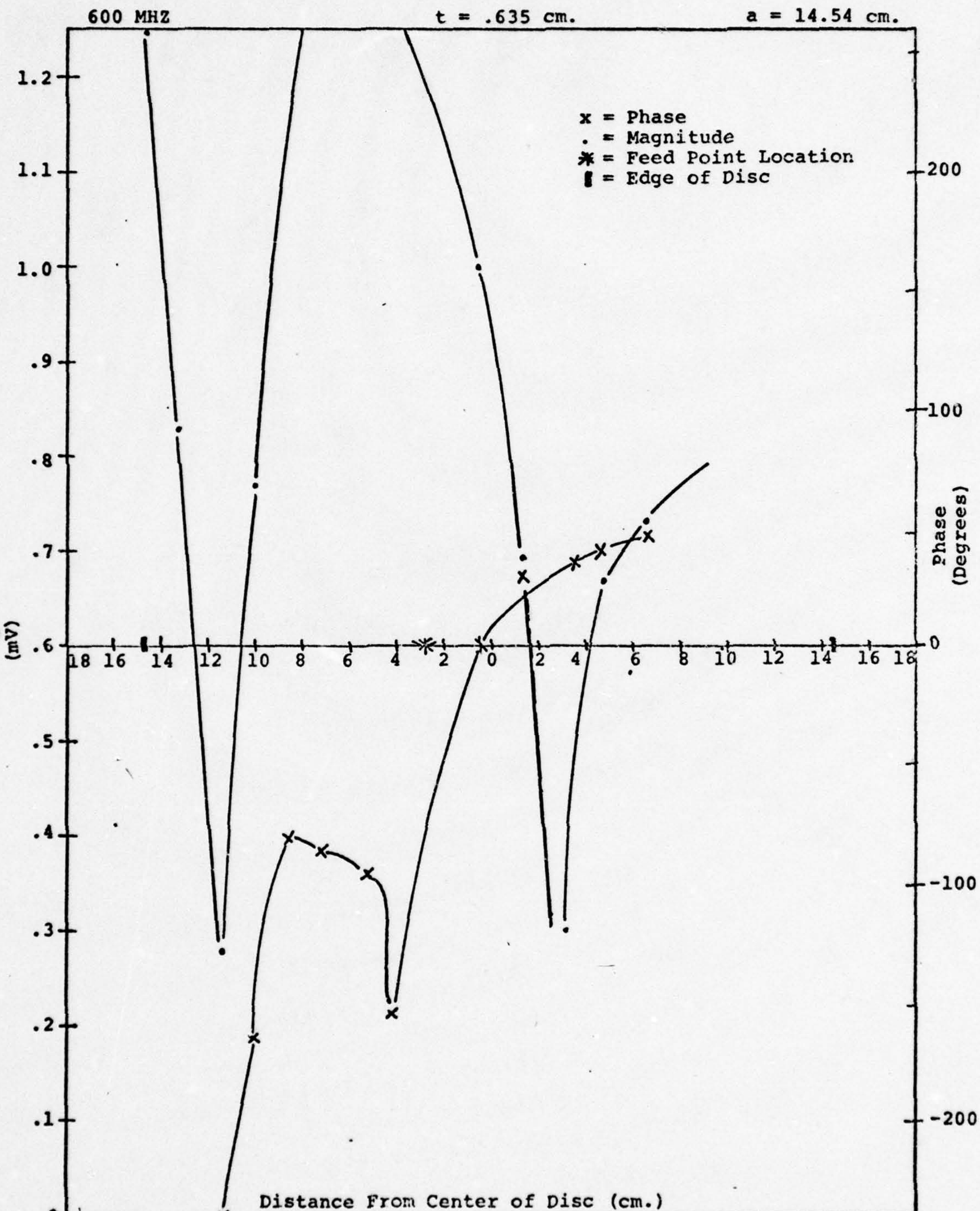


Figure 3-28
Normalized $|E_z|$ And Phase Vs. r

far edge of the disc.

All of the electric field graphs have been normalized to a magnitude of one and a phase of zero at the field point nearest and just inside the feed. The data for the field points are found in Appendix VII.

3-4 Printed Circuit Antenna Impedance

Two printed circuit antennas were fabricated with design resonant frequencies of 1 GHZ and 2 GHZ respectively. These antennas were fabricated on teflon-fiberglass printed circuit board with the design parameters shown in Table 6.

TABLE 6

Design Parameters Printed Circuit Board

f	d(mm)	d(inch)	kd
1 GHZ	1.6	.063	.053
2 GHZ	1.6	.063	.105

a_1 = 5.57 cm. ε_r = 2.47 ka = 1.84

a_2 = 2.78 cm.

The impedance was measured for both the antennas and the results are shown in Figures 3-29 through 3-34. The measurements were first taken with the center not grounded as shown in Figures 3-29 and 3-30. They were then remeasured with the center being grounded. As can be seen in Figures 3-31 and 3-32 the grounding had very little effect on the resonant frequency or the magnitude of the resistance. This supports the earlier results found with the model. The feed

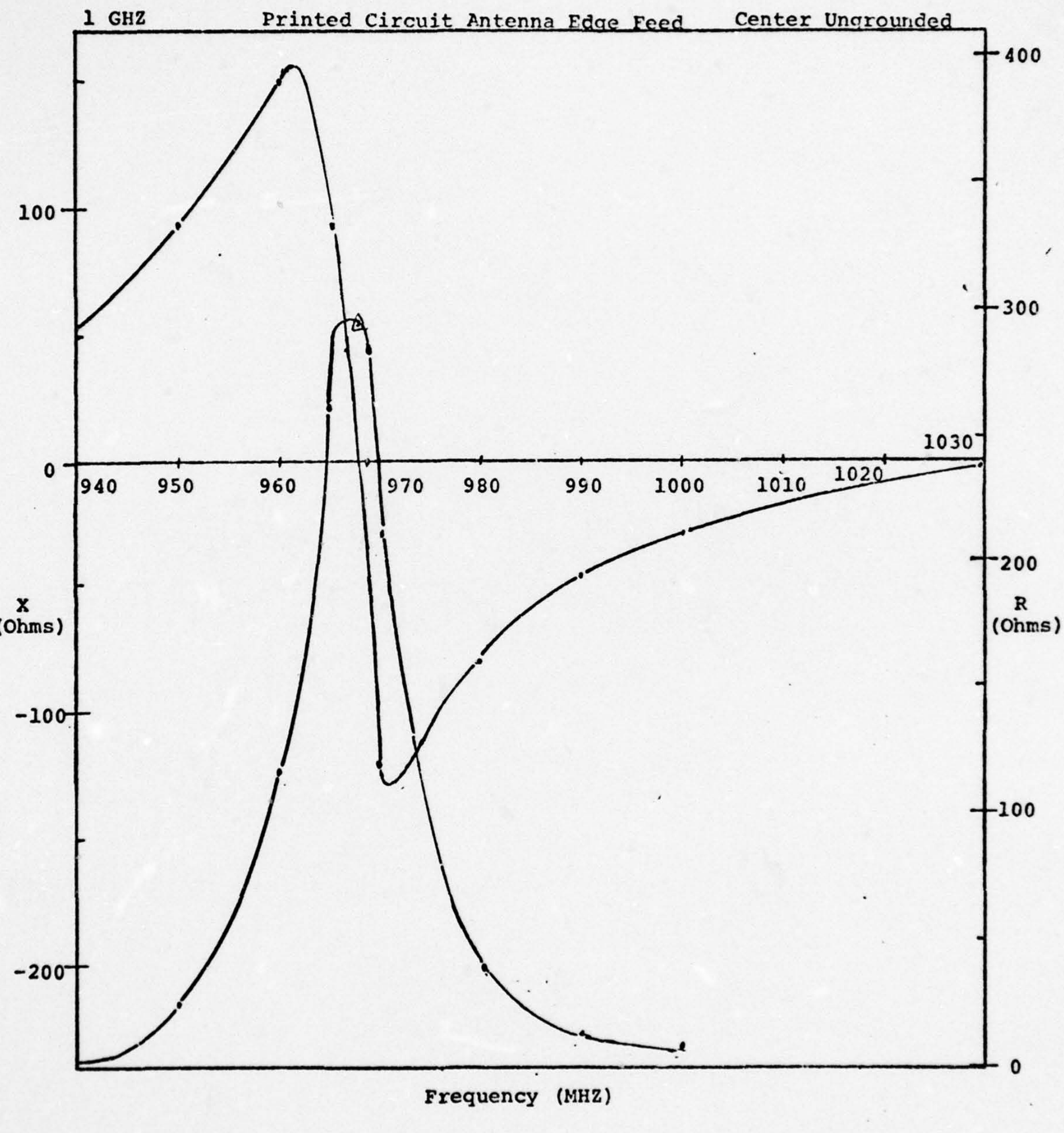


Figure 3-29

Resistance and Reactance Vs. Frequency

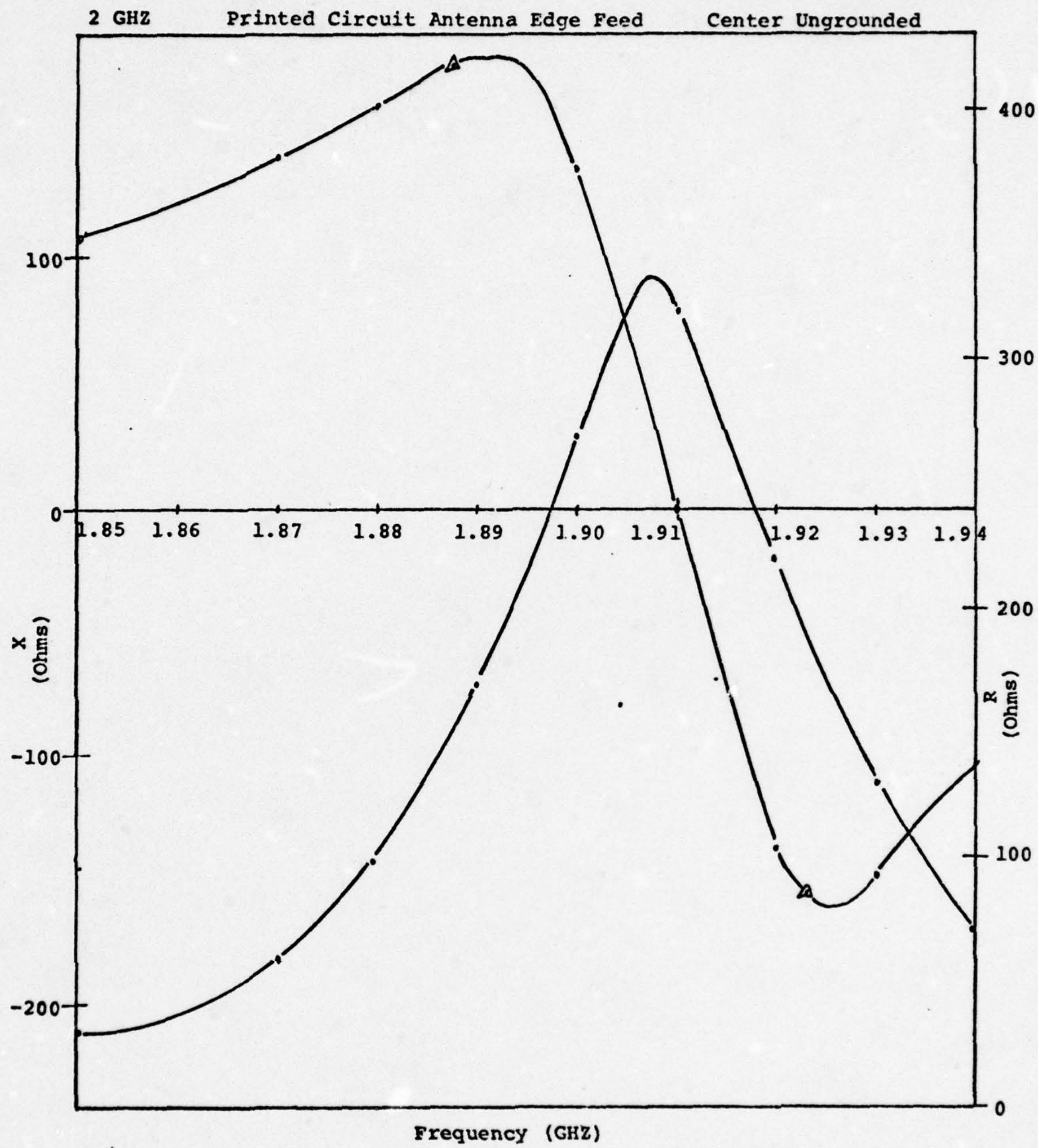


Figure 3-30

Resistance and Reactance Vs. Frequency

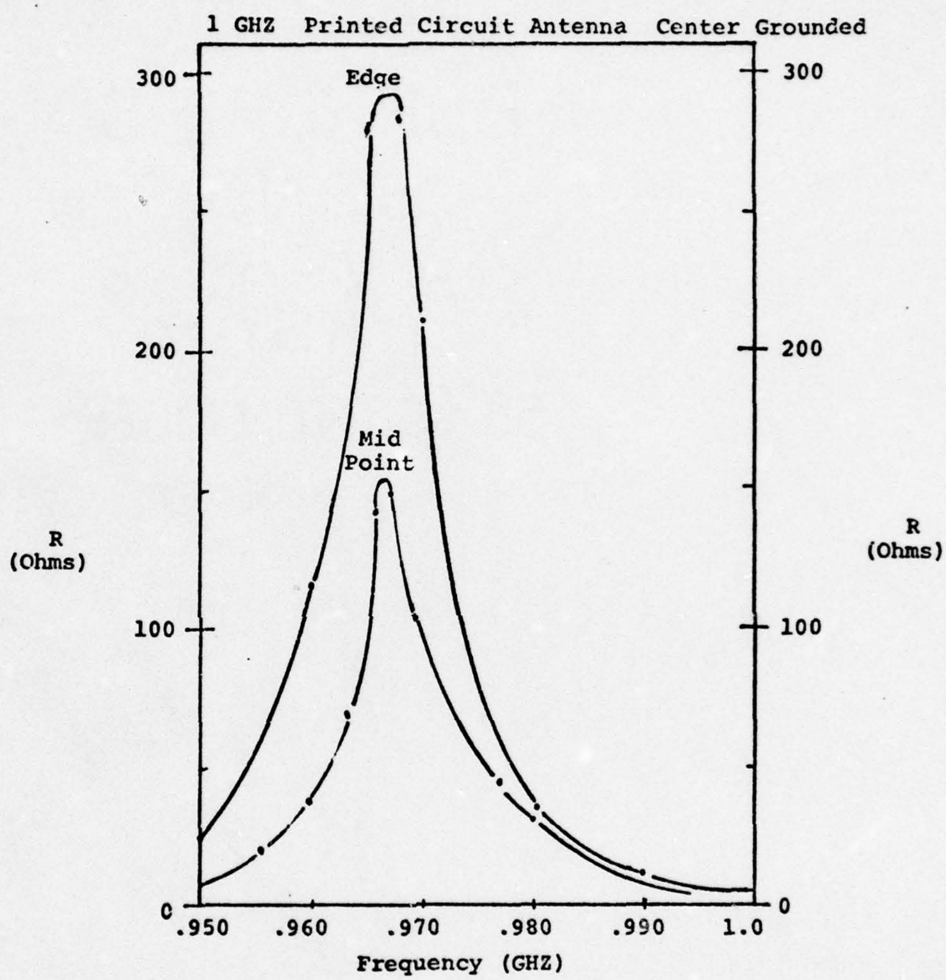


Figure 3-31

Resistance Vs. Frequency

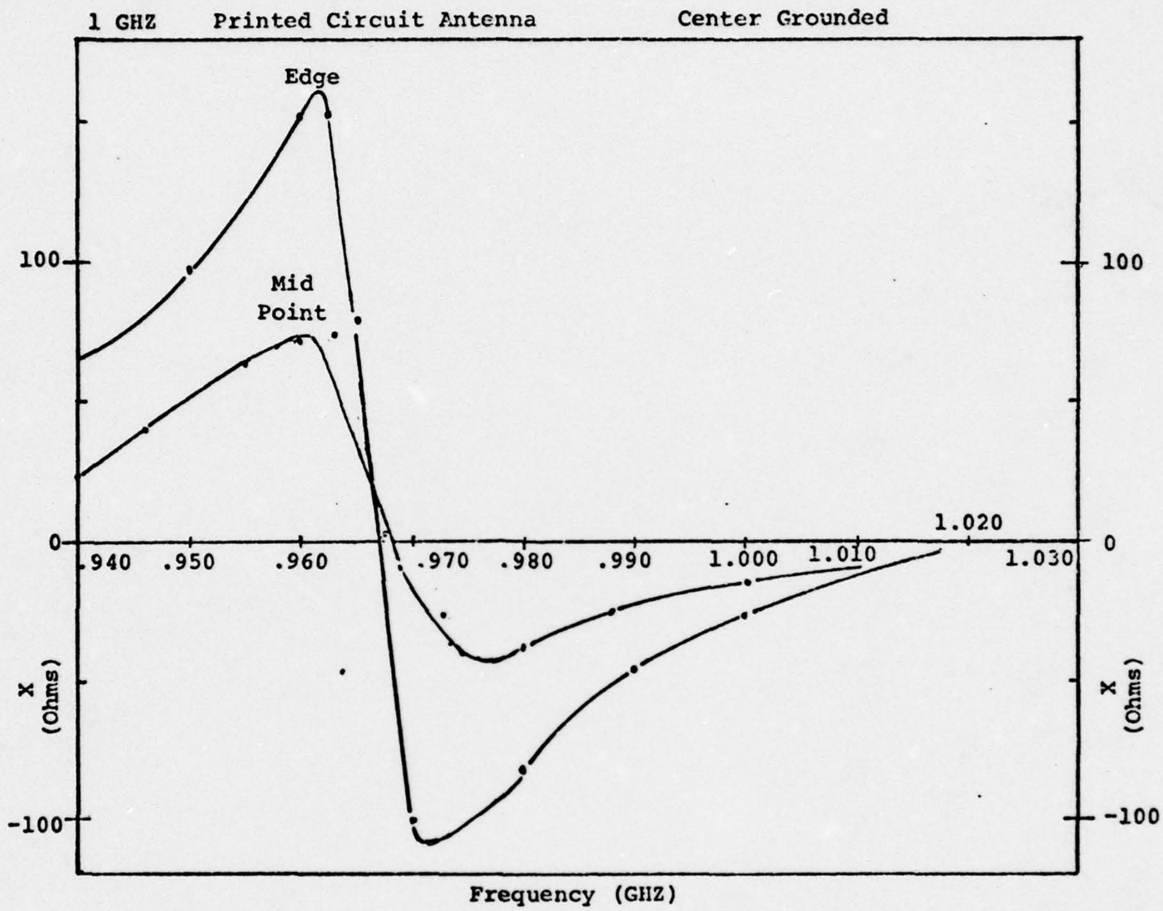


Figure 3-32

Reactance Vs. Frequency

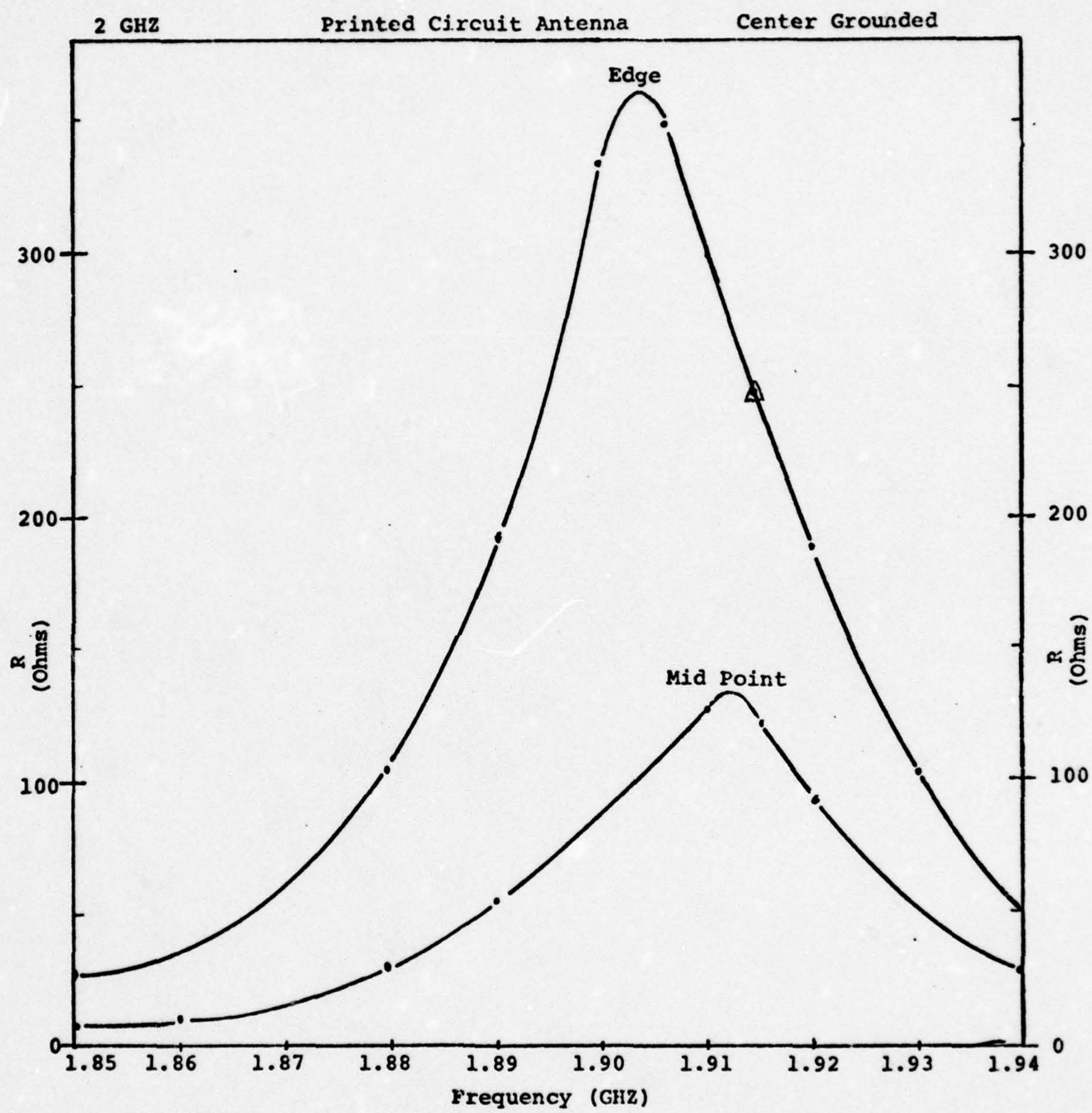


Figure 3-33

Resistance Vs. Frequency

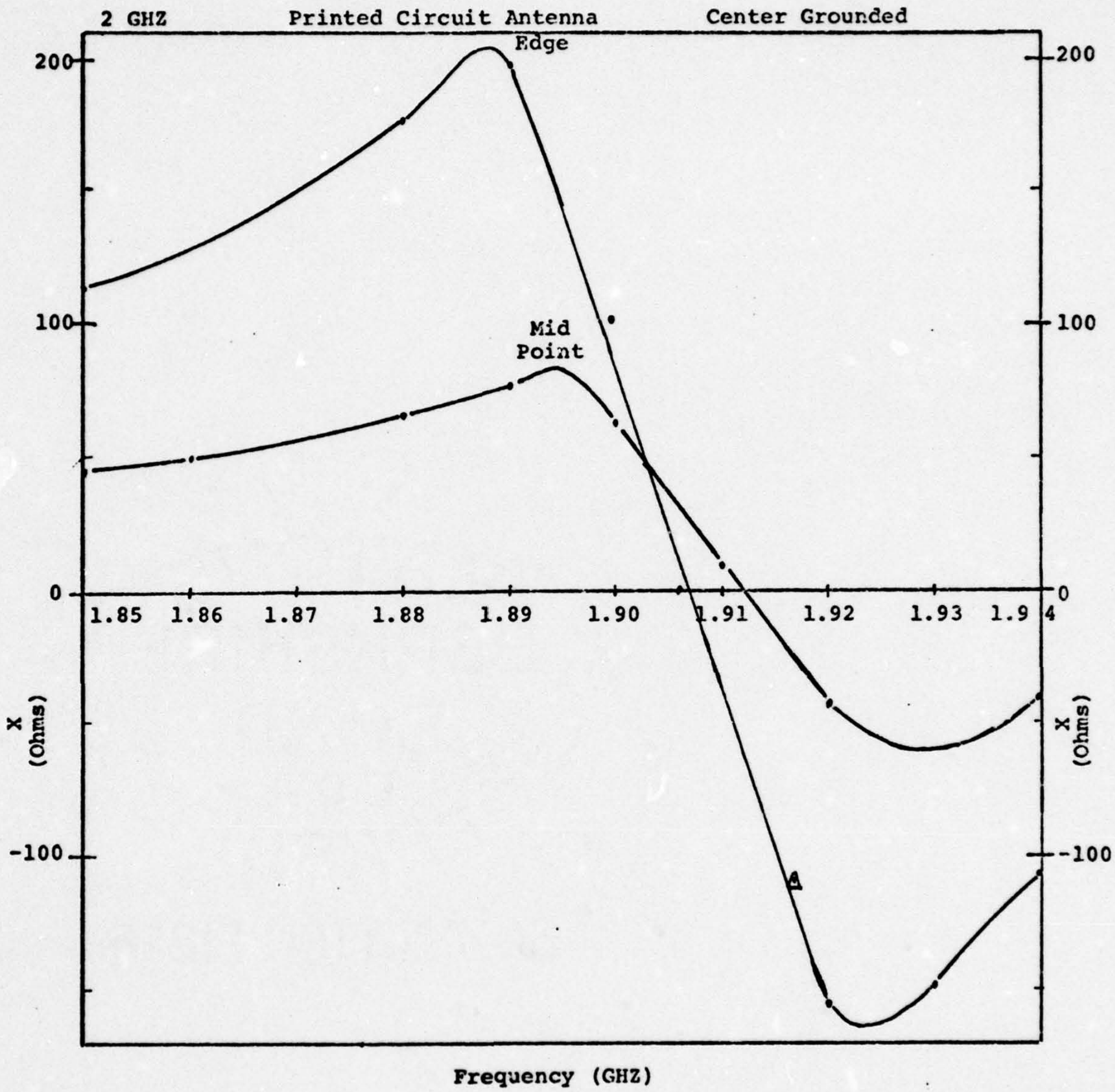


Figure 3-34

Reactance Vs. Frequency

point was moved to $\frac{a}{2}$ for each antenna and, as in the case of the model, there was a drop in the magnitude of the resistance and only a slight variation in the resonant frequency.

The 1 GHZ antenna had an average resonant frequency of 968 MHZ or 3.2% below the design resonance. The 2 GHZ antenna had a 1.91 GHZ average resonant frequency or 4.55% below design resonance. Again the printed circuit antenna bears out the results of the model in that the resonant point is below design. Also it shows that the thinner the dielectric, the closer to design frequency the antenna approaches. For each different dielectric this average resonant frequency seems to vary almost linearly with the electrical thickness, kd as shown in Figure 3-35.

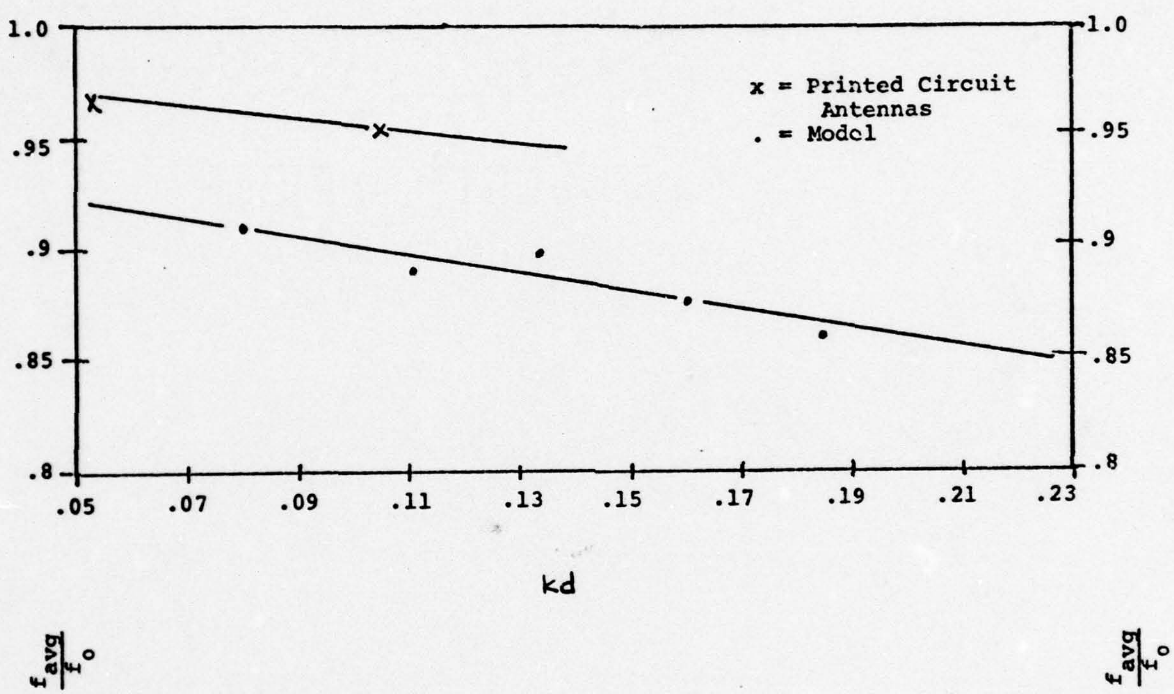


Figure 3-35

Normalized Average Frequency Vs.
The Electrical Length of Dielectric

CHAPTER IV

COMPARISONS, CONCLUSIONS AND PREDICTIONS

4-1 Comparisons

4-1a Impedance

The variations in impedance for both the model and the printed circuit antennas were found to be quite similar. Even though the kd for the model and that of various printed circuit antennas were different, it was observed to have little effect on the general characteristics of the circular disc or printed circuit antenna.

Some important characteristics that can be associated with the printed circuit antenna are as follows:

1. The resonant frequency is a function of the dielectric thickness. The thinner the dielectric, the closer to the design resonant frequency the antenna approaches. This was shown both with the model and the actual printed circuit antenna. The grounding of the radiator at the center did not effect this result.

2. The magnitude of the impedance was found to decrease as the feed point was moved closer to the center. This occurred for both the model and the actual printed circuit antenna. Again grounding the center of the disc or radiator had no effect on this result.

3. The resonant frequency was found to vary a small amount with the movement of the feed point. However, this change in frequency was not constant and varied only over a

small percentage of the design frequency. This can be seen in Figures 4-1 and 4-2. This occurred for both grounded and ungrounded radiators of both the model and the printed circuit antenna.

4. It was shown on the model that only for feed points located greater than 39% of the way from the center to the edge that actual resonance could take place.

4-1b Fields Compared With Theory

The electric field measured on the model did compare reasonably well with that predicted by theory. The magnitude of the field should approach zero at the center of the disc. In actuality the magnitude does approach zero but not at the exact center of the disc. The field tends to be offset slightly but still fairly reasonable agreement is found. The phase on the other hand does have some variation from the theory but does follow the pattern of being zero at the field magnitude maximum and changing approximately 180° as the field goes through a minimum. Since no theory was developed for the field except for an edge feed, the rest of the fields cannot be compared. However, there seems to be a tendency for the field magnitude minimum to shift toward the far edge of the radiator as the feed point moves toward the center of the disc.

4-2 Conclusions and Predictions

The printed circuit antenna is a low profile antenna making it very desirable from an aerodynamic standpoint.

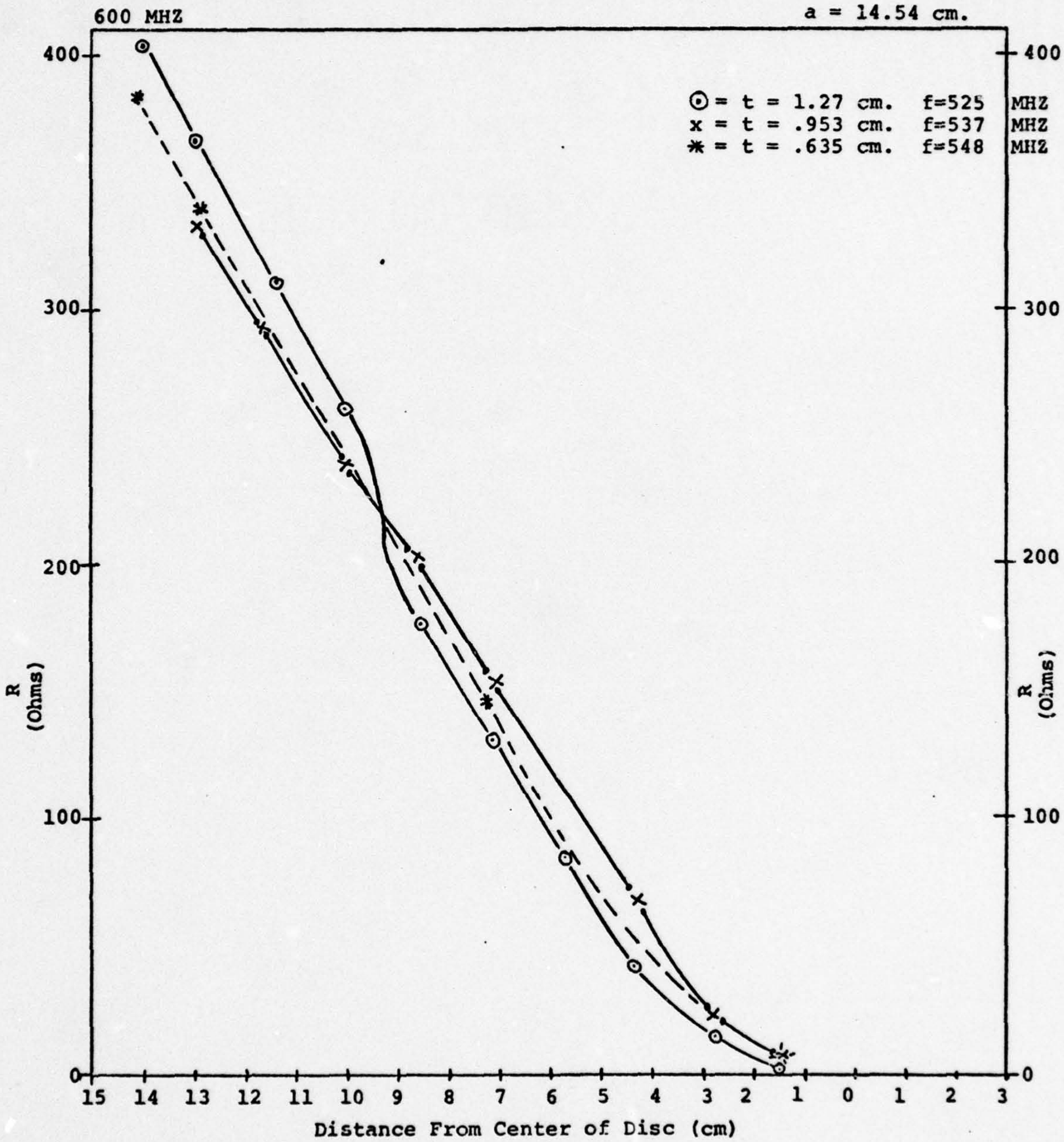


Figure 4-1

Resistance Vs. Feed Point Location

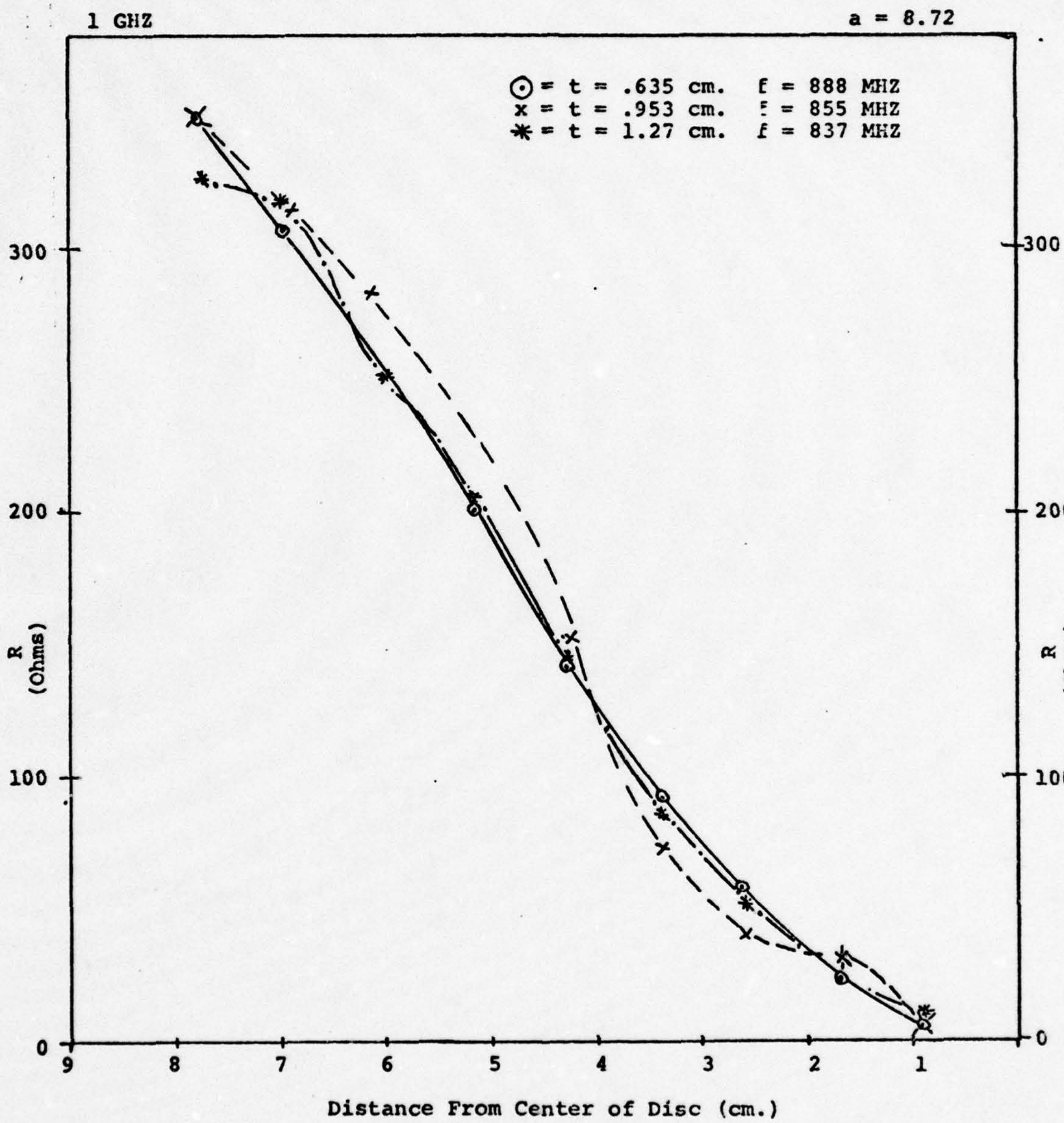


Figure 4-2

Resistance Vs. Feed Point Location

With results found here for the impedance, a feed point can be located which will match a wide range of impedances. The measurements of the fields allows the n=1 mode of excitation to be confirmed.

With these facts and data a theory for the impedance should be shortly forthcoming.

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Appendix I

Impedance Using Slotted Line

(Single Minimum Method)

Example from 1 GHZ printed circuit antenna grounded at the center and fed at the mid point.

$$f = 967 \text{ MHZ}$$

	VSWR	
a_1 = 5.52 cm.	9.5	s_1 = 13.52 cm.
a_2 = 21.05 cm.	8.5	s_2 = 29.02 cm.

$\lambda_{o_{theory}}$ = 31.02 cm.

$\lambda_{o_{measured}}$ = (29.02 - 13.52)·2 = 31.0 cm.

$a_1 - s_1$ =-8.0 cm.

$a_2 - s_2$ =-7.97

> average = -7.985 cm.

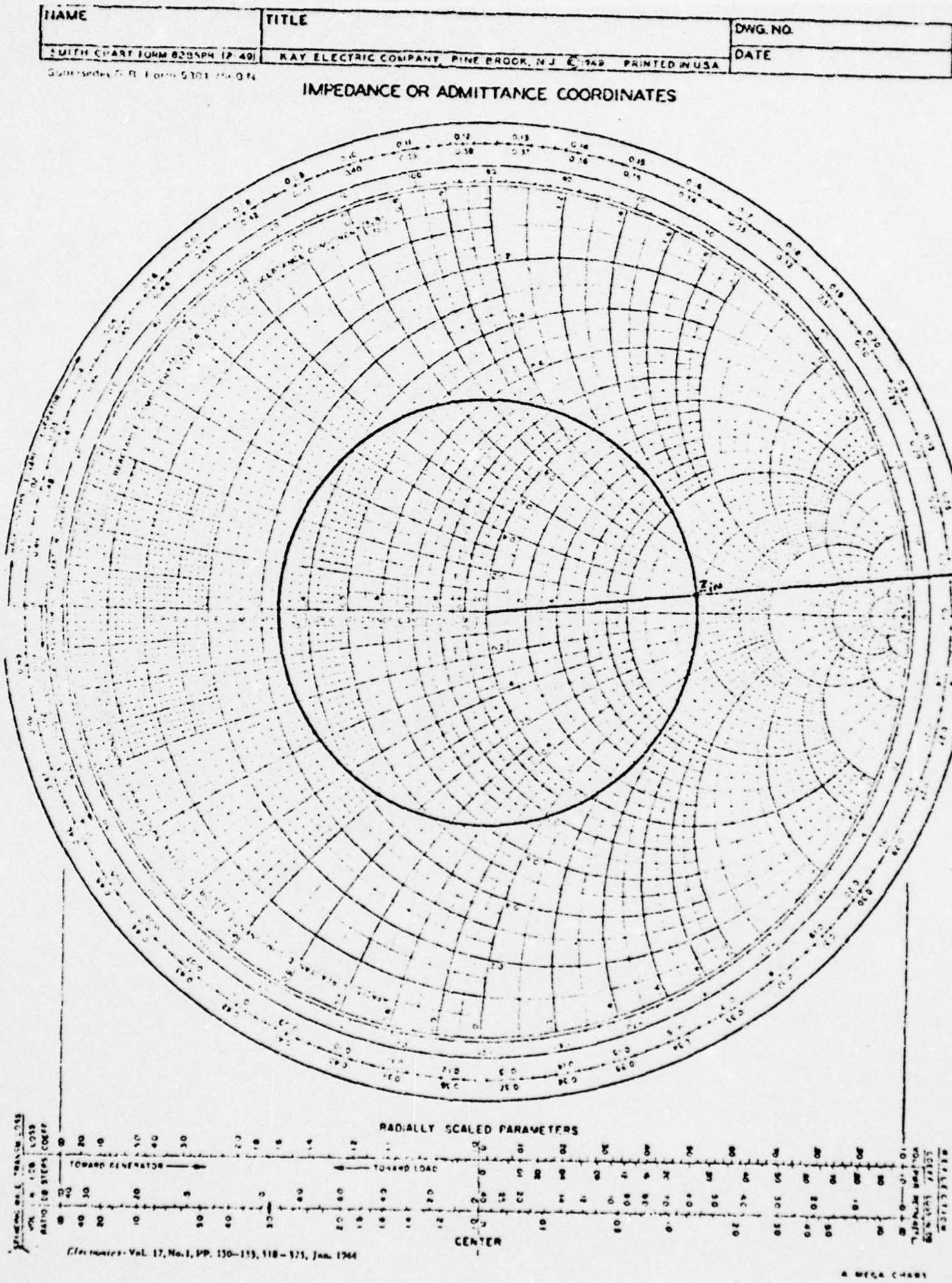
$$-\frac{7.985}{31.0} = -.2575\ \lambda_g \text{ toward load}$$

SWR average = 9

From Smith Chart

$$Z_{normal} = 3 + j.04$$

$$50(Z_N) = Z_{in} = 150 + j2$$



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Appendix II

Program for Finding Impedance from the Reflection Coefficient

```
$$WATFIV TIME=200,LINES=2000
C PROGRAM FOR FINDING ZL USING REFLECTION COEFFICENT
      DIMENSION C(200),A(200),R(200),X(200),F(200),Y(200)
      WRITE (6,100)
  100 FORMAT(1H1,8X,'FREQUENCY',5X,'REFLECTION MAG.',9X,'REFLECTION ANG.
     C',13X,'R',17X,'X'//)
      I=0
   50 READ (5,200,END=150) G,B,T
  200 FORMAT(3F10.5)
      I=I+1
      Y(I)=G
      C(I)=B
      A(I)=(T*3.1412)/180.
       D=1.-(2.*C(I)*(COS(A(I))))+((C(I)**2)*(COS(A(I))**2))
     C+((C(I)**2)*(SIN(A(I))**2))
       R(I)=50.*((1.-((C(I)**2)*(COS(A(I))**2))-((C(I)**2)
     C*(SIN(A(I))**2)))/D)
       X(I)=50.*((2.*C(I)*SIN(A(I)))/D)
      F(I)=(A(I)*180.)/3.1412
       GO TO 50
  150 DO 20 J=1,I
      WRITE(6,300) Y(J),C(J),F(J),R(J),X(J)
  300 FORMAT(1H0,8X,F10.5,4X,F10.5,13X,F10.5,14X,F10.5,4X,F10.5)
   20 CONTINUE
       STOP
          END
```

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Appendix III

Data for 600 MHZ Circular Disc Ungrounded

$t = .635$ cm.

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FREQUENCY	REFLECTION MAG.	REFLECTION ANG.	R	X	
.40000	.95000	109.00000	1.93402	35.63824	
.50000	.93000	63.00000	6.62093	81.21324	
.51000	.90000	58.00000	11.09875	89.16186	
.52000	.88000	49.00000	18.20547	107.18028	
.53000	.84000	34.00000	47.06677	150.17573	
.54000	.81000	18.00000	149.04380	216.93349	1
.54800	.77000	.00000	384.78265	.00000	
.56000	.65000	-15.00000	173.12665	-100.85524	
.57000	.67000	-37.00000	72.76913	-106.47265	
.58000	.69000	-72.00000	24.96068	-62.52754	
.60000	.74000	-134.00000	8.78316	-20.67505	
.65000	.90000	155.00000	2.76075	11.06136	
.75000	.97000	105.00000	2.87950	38.29529	
.90000	.8[illegible]000	35.00000	54.66362	139.33485	
.92500	.72000	.00000	307.14289	.00000	
.40000	.95000	116.00000	1.78247	31.22370	
.50000	.93000	69.00000	5.63822	72.46459	
.52000	.88000	53.00000	15.77527	98.27912	
.53000	.83000	38.00000	40.85708	134.20578	
.54000	.81000	21.00000	119.68143	202.01652	
.54900	.74000	.00000	334.61539	.00000	2
.56000	.64000	-15.00000	170.43477	-95.62358	
.57000	.68000	-38.00000	68.81087	-107.15997	
.58000	.70000	-71.00000	24.66152	-64.00657	
.60000	.76000	-131.00000	8.20359	-22.28494	
.65000	.90000	164.00000	2.68355	7.01629	
.75000	.93000	116.00000	2.52067	31.19512	
.90000	.79000	44.00000	38.55877	112.57346	
.92800	.67000	.00000	255.03031	.00000	

t = .635 cm.

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.40000	.96000	120.00000	1.36056	28.86020	
.50000	.93000	73.00000	5.11430	67.33165	
.52000	.87000	57.00000	15.02386	90.17830	
.53000	.82000	40.00000	39.37546	126.69163	
.54000	.79000	23.00000	110.77298	181.90525	3
.54800	.73000	.00000	320.37039	.00000	
.56700	.61000	-20.00000	139.12721	-92.44449	
.57000	.65000	-42.00000	63.27630	-95.30136	
.60000	.74000	-134.00000	8.78316	-20.67505	
.65000	.89000	166.00000	2.95391	6.12728	
.75000	.94000	122.00000	2.02124	27.68949	
.90000	.77000	52.00000	31.57558	94.11626	
.92800	.59000	.00000	193.90244	.00000	
.40000	.95000	120.00000	1.70929	28.85093	
.50000	.97000	75.00000	4.88359	64.94143	
.52000	.87000	58.00000	14.56293	88.38916	
.53000	.83000	43.00000	34.63917	118.25162	
.54000	.77000	25.00000	103.24599	165.04040	
.54900	.69000	.00000	272.58065	.00000	4
.56000	.60000	-19.00000	141.99407	-86.66847	
.57000	.63000	-45.00000	59.61159	-88.05505	
.60000	.73000	-143.00000	8.65438	-16.28627	
.65000	.89000	161.00000	2.99144	8.34699	
.75000	.93000	121.00000	2.39331	28.24822	
.90000	.76000	58.00000	27.35894	83.48436	
.92900	.47000	.00000	138.67925	.00000	
.40000	.93000	131.00000	3.17671	22.71872	
.50000	.95000	90.00000	2.56292	49.94409	
.52000	.88000	75.00000	8.55453	64.46058	5
.53000	.61000	58.00000	21.56229	86.13187	
.54000	.74000	38.00000	59.32826	119.48039	

t = .635 cm.

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.55000	.61000	.00000	206.41026	.00000	
.56000	.53000	-26.00000	109.56815	-70.79333	
.57000	.53000	-58.00000	50.00196	-62.50140	
.58000	.60000	-106.00000	18.92933	-34.11984	5
.65000	.91000	158.00000	2.44500	9.70554	
.75000	.94000	127.00000	1.93061	24.90795	
.90000	.86000	81.00000	12.95499	56.86728	
.93600	.10000	.00000	61.11111	.00000	
.40000	.96000	135.00000	1.19554	20.70919	
.50000	.96000	100.00000	1.73867	41.93450	
.52000	.89000	86.00000	6.23351	53.23939	
.53000	.81000	71.00000	15.23782	67.86604	
.54000	.71000	50.00000	41.93850	91.98590	
.55100	.51000	.00000	154.08163	.00000	6
.56000	.39000	-34.00000	83.88101	-43.14470	
.57000	.45000	-79.00000	38.69032	-42.85940	
.58000	.59000	-139.00000	14.56159	-17.29833	
.65000	.93000	150.00000	1.94366	13.38733	
.75000	.94000	125.00000	1.96522	26.00537	
.90000	.85000	91.00000	7.92028	48.51342	
.93200	.37000	90.00000	37.96333	32.54880	
.40000	.96000	136.00000	1.18704	20.20015	
.50000	.96000	104.00000	1.64315	39.04721	
.52000	.91000	90.00000	4.70252	49.78819	
.53000	.80000	78.00000	13.77121	59.86571	
.54000	.68000	57.00000	37.25318	79.03134	7
.55100	.39000	.00000	113.93443	.00000	
.55000	.27000	-71.00000	51.67700	-28.45845	
.57000	.45000	-130.00000	22.39145	-19.36205	
.58000	.66000	-170.00000	10.31636	-4.19852	
.65000	.95000	136.00000	1.49135	20.19448	

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$t = .635$ cm

.75000	.94000	117.00000	2.12667	30.60850	
.90000	.89000	92.00000	5.60721	47.97892	7
.93000	.60000	90.00000	23.53349	44.12529	
.40000	.96000	141.00000	1.14843	17.70628	
.50000	.98000	118.00000	.68747	30.04762	
.52000	.92000	110.00000	3.10265	34.92877	
.53000	.85000	100.00000	6.87788	41.49624	
.54000	.71000	87.00000	17.34506	49.59868	
.55000	.27000	65.00000	54.88288	28.97017	8
.56000	.20000	144.00000	35.20267	8.62523	
.56800	.24000	180.00000	30.64516	.00613	
.57000	.37000	-171.00000	23.10539	-3.10626	
.58000	.72000	167.00000	8.24269	5.55288	
.65000	.97000	130.00000	.92706	23.31743	
.90000	.93000	98.00000	3.18127	43.37340	
.40000	.97000	145.00000	.83718	15.76961	
.50000	.99000	128.00000	.31107	24.39451	
.52000	.97000	124.00000	.97676	26.58623	
.53000	.94000	121.00000	2.04107	28.26163	
.54000	.84000	116.00000	6.02863	30.92460	
.55000	.79000	118.00000	7.94545	29.49154	9
.56000	.67000	105.00000	15.34738	36.04781	
.57000	.37000	135.00000	25.99691	15.76541	
.58000	.70000	150.00000	9.43673	12.95972	
.60000	.95000	140.00000	1.45193	18.19360	
.80000	.95000	105.00000	2.03648	38.33537	
.90000	.95000	97.00000	2.28481	44.19385	
.40000	.96000	145.00000	1.12192	15.76641	
.50000	.99000	130.00000	.30593	23.32330	
.54000	.92000	125.00000	2.64703	25.97958	10
.55000	.77000	126.00000	8.14935	24.94518	

E7372 DATE 072176 PAGE 5

$t = .635$ cm.

.56000	.85000	133.00000	4.81514	21.57942
.57000	.93000	131.00000	2.18979	22.75873
.65000	.99000	119.00000	.33848	29.45999
.75000	.96000	108.00000	1.55897	36.31300
.96000	.96000	93.00000	1.93897	47.42031
1.16000	.62000	.00000	213.15789	.00000

10

t = .953cm

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FREQUENCY	REFLECTION MAG.	REFLECTION ANG.	R	X	
.40000	.95000	89.00000	2.60839	50.82218	
.50000	.86000	41.00000	25.29103	129.43102	
.52000	.82000	25.00000	88.05627	186.27633	
.53000	.80000	10.00000	279.93118	216.01565	
.53600	.76000	.00000	366.66668	.00000	1
.55000	.72000	-20.00000	145.74407	-149.02753	
.56000	.68000	-43.00000	57.47618	-99.15331	
.58000	.62000	-97.00000	20.04875	-40.08413	
.60000	.66000	-151.00000	10.89623	-12.36210	
.65000	.80000	135.00000	6.49576	20.42022	
.75000	.92000	82.00000	4.83020	57.29725	
.90200	.66000	.00000	244.11765	.00000	
.40000	.91000	95.00000	2.84310	45.74550	
.50000	.83000	44.00000	22.19404	120.26465	
.52000	.82000	28.00000	73.02104	171.59607	
.53000	.79000	10.00000	276.00029	201.42379	
.53500	.74000	.00000	334.61539	.00000	
.55000	.70000	-20.00000	146.20769	-137.25484	
.56000	.64000	-48.00000	53.38028	-85.99575	2
.57000	.65000	66.00000	32.31415	66.44869	
.59000	.62000	-129.00000	14.22047	-22.26581	
.60000	.7[illegible]000	-150.00000	9.43673	-12.95972	
.65000	.82000	150.00000	5.29683	13.26577	
.70000	.92000	115.00000	2.92728	31.78461	
.80000	.90000	76.00000	6.91286	63.54225	
.90500	.64000	.00000	227.77779	.00000	
.40000	.94000	105.00000	2.45594	38.31715	
.50000	.89000	52.00000	14.93396	100.74762	
.52000	.80000	28.00000	79.21212	165.26027	3

t= .953 cm

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.53000	.78000	10.00000	271.58994	187.85038	
.53500	.72000	.00000	307.14289	.00000	
.55000	.68000	-24.00000	122.21003	-125.73283	
.56000	.62000	-50.00000	52.41471	-80.87056	
.57000	.64000	-71.00000	29.73752	-60.95583	3
.60000	.70000	-148.00000	9.52549	-13.86370	
.65000	.81000	150.00000	4.65786	13.29763	
.70000	.90000	120.00000	3.50606	28.76967	
.80000	.94000	85.00000	5.74767	54.24538	
.97500	.58000	.00000	188.09524	.00000	
.40000	.92000	110.00000	3.10265	34.92877	
.50000	.90000	58.00000	11.09875	89.16186	
.52000	.82000	40.00000	43.45316	124.12555	
.53000	.74000	18.00000	161.55020	163.29635	
.54000	.65000	.00000	235.71429	.00000	
.55000	.64000	-21.00000	137.56079	-106.86503	4
.56000	.56000	-52.00000	53.33299	-73.45835	
.57000	.60000	-80.00000	27.79187	-51.31651	
.60000	.74000	-158.00000	7.74753	-9.50272	
.70000	.92000	125.00000	2.64703	25.97958	
.95000	.42000	.00000	122.41380	.00000	
.40000	.94000	116.00000	2.14974	31.21071	
.50000	.86000	65.00000	12.85957	76.97698	
.52000	.80000	47.00000	32.80585	106.62393	
.53000	.70000	25.00000	115.31322	133.76251	
.54000	.62000	7.00000	200.33784	49.17298	5
.54400	.60000	.00000	200.00000	.00000	
.56000	.52000	-60.00000	48.62171	-60.01731	
.57000	.50000	-65.00000	32.25364	-42.84051	
.59000	.64000	-160.00000	11.30059	-8.38750	
.60000	.72000	-174.00000	7.82453	-2.56567	

E7368 DATE 072176 PAGE 3

$t = .953$ cm.

.70000	.96000	122.00000	3.43773	27.62383	
.80000	.91000	94.00000	4.39713	46.44209	5
.91800	.10000	2.00000	73.43089	1.01017	
.40000	.94000	124.00000	1.98333	26.56152	
.50000	.90000	78.00000	6.61809	61.32539	
.52000	.80000	61.00000	20.83048	80.96624	
.53000	.76000	40.00000	61.08381	107.77208	
.54000	.58000	17.00000	146.11983	74.66953	
.54700	.53000	.00000	162.76596	.00000	
.56000	.39000	-70.00000	47.89246	-41.39795	6
.57000	.44000	-118.00000	25.09749	-24.18560	
.59000	.78000	179.00000	8.82421	.43221	
.60000	.80000	167.00000	5.62700	5.63466	
.70000	.92000	115.00000	2.92728	31.78461	
.80000	.90000	95.00000	4.83090	45.59306	
.91900	.30000	82.00000	45.21111	29.51867	
.40000	.96000	122.00000	1.33395	27.70906	
.50000	.90000	85.00000	5.74787	54.24538	
.52000	.79000	70.00000	17.34686	68.51210	
.53000	.64000	51.00000	48.87747	82.34473	
.54000	.42000	38.00000	80.05006	50.25977	
.55000	.30000	.00000	92.85714	.00000	7
.56000	.42000	-160.00000	20.94990	-7.31498	
.58000	.65000	167.00000	10.73790	5.44607	
.60000	.84000	147.00000	4.72662	14.69758	
.70000	.95000	108.00000	1.95846	36.29963	
.80000	.96000	90.00000	5.24964	49.73347	
1.12800	.24000	30.00000	73.40797	18.69261	
.40000	.98000	128.00000	.32526	24.39219	
.50000	.92000	98.00000	3.65351	43.34136	8
.52000	.83000	87.00000	9.71151	51.74816	

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AN EXPERIMENTAL INVESTIGATION OF THE CIRCULAR DISC ANTENNA.(U)
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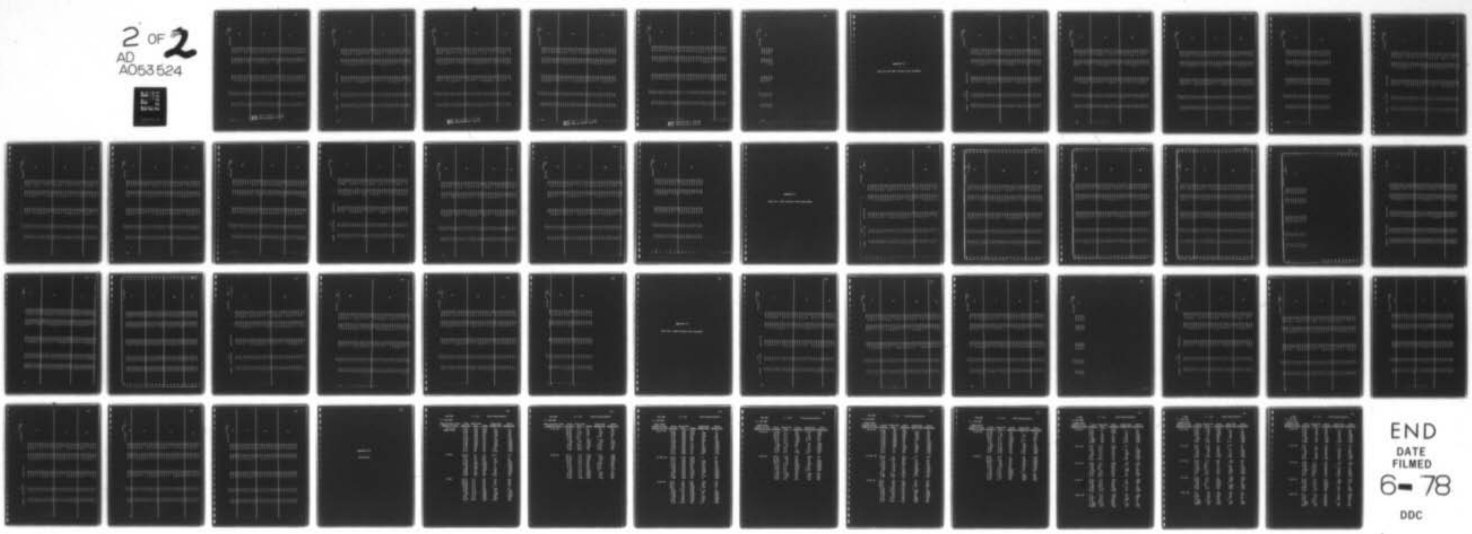

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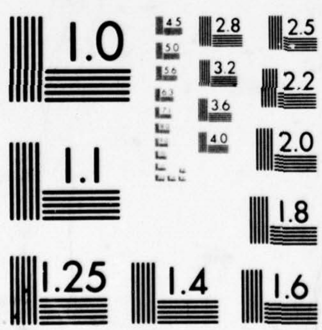

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

t=.953cm.

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.53000	.72000	77.00000	20.16354	58.74215	
.54000	.52000	68.00000	41.42319	54.74341	
.55000	.23000	45.00000	65.08393	22.35003	8
.55500	.10000	180.00000	40.90909	.00325	
.57000	.58000	157.00000	13.80182	9.43444	
.60000	.90000	130.00000	3.20229	23.24539	
.70000	.96000	104.00000	1.64315	39.04721	
1.26500	.60000	.00000	200.00000	.00000	
.40000	.98000	130.00000	.61494	23.32112	
.50000	.97000	107.00000	1.17839	36.99380	
.52000	.89000	102.00000	4.80850	40.27174	
.53000	.79000	96.00000	10.50631	43.91963	
.54000	.67000	94.00000	17.86850	43.34204	
.55000	.44000	100.00000	29.95050	32.16877	9
.56000	.60000	130.00000	15.01583	21.57287	
.58000	.90000	122.00000	3.43773	27.62383	
.60000	.98000	115.00000	.71011	31.85776	
.65000	.99000	103.00000	.41030	39.77933	
.70000	.96000	95.00000	1.87691	45.79098	
1.10000	.59000	.00000	195.90244	.00000	
.40000	.96000	136.00000	.58755	20.20754	
.50000	1.00000	122.00000	.00000	27.72415	
.52000	.98000	121.00000	.66679	28.29354	
.53000	.92000	120.00000	2.77659	28.80943	
.54000	.90000	118.00000	3.57864	29.93859	10
.55000	.83000	117.00000	6.36940	30.28612	
.55100	.80000	120.00000	7.37815	28.40279	
.57000	.93000	121.00000	2.39331	28.24822	
.60000	1.00000	118.00000	.00000	30.05179	
.70000	1.00000	105.00000	.00000	38.37545	
.80000	.98000	96.00000	.91461	45.02136	

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$t = 1.27$ cm

FREQUENCY	REFLECTION MAG.	REFLECTION ANG.	R	X	
.40000	.94000	72.00000	4.46879	68.64020	
.47000	.90000	44.00000	18.44416	121.36843	
.50000	.86000	25.00000	72.04876	201.09969	
.51000	.82000	19.00000	134.56297	219.28814	
.52000	.81000	8.00000	331.55432	217.33960	1
.52500	.78000	.00000	404.54552	.00000	
.54000	.75000	-17.00000	170.87455	-156.13598	
.55000	.66000	-35.00000	79.65867	-106.84739	
.58000	.52000	-111.00000	22.20508	-29.55241	
.60000	.59000	-171.00000	12.96796	-3.68067	
.70000	.91000	85.00000	5.14936	54.31074	
.80000	.90000	51.00000	14.03110	103.29371	
.89200	.66000	.00000	244.11765	.00000	
.40000	.94000	79.00000	3.81749	60.52225	
.47000	.91000	48.00000	14.08692	110.82658	
.50000	.85000	27.00000	66.78911	185.73261	
.51000	.81000	21.00000	119.68143	202.01652	
.52000	.79000	9.00000	295.76271	194.44947	2
.52500	.76000	.00000	366.66668	.00000	
.54000	.71000	-20.00000	146.09762	-143.06618	
.55000	.64000	-37.00000	76.22306	-99.44123	
.58000	.54000	-110.00000	21.32787	-30.55739	
.60000	.60000	-164.00000	12.73178	-6.58825	
.65000	.81000	129.00000	6.42745	23.53548	
.75000	.90000	75.00000	7.06929	64.68734	
.85000	.83000	35.00000	47.27462	144.67052	
.89300	.62000	.00000	213.15789	.00000	
.40000	.94000	85.00000	3.38490	54.46131	
.47000	.90000	53.00000	13.07519	98.91856	3

$t = 1.27$ cm.

.50000	.82000	30.00000	64.98333	162.63823	
.51000	.78000	22.00000	120.89022	180.38353	
.52000	.76000	10.00000	261.75396	163.54205	
.52600	.72000	.00000	307.14289	.00000	
.54000	.64000	-23.00000	127.61063	-108.08791	3
.55000	.60000	-44.00000	64.42362	-83.90242	
.58000	.53000	-120.00000	19.85740	-25.35335	
.60000	.62000	-170.00000	11.81356	-4.14082	
.65000	.81000	132.00000	6.27613	21.97662	
.80000	.83000	67.00000	10.38219	74.55238	
.85000	.81000	42.00000	38.03311	119.87024	
.89400	.52000	.00000	158.33333	.00000	
.40000	.95000	92.00000	3.50102	48.17149	
.49000	.90000	60.00000	10.44190	85.66360	
.50000	.82000	36.00000	47.40455	139.47351	
.51000	.78000	29.00000	80.26387	154.99712	
.52000	.74000	15.00000	191.66692	162.26673	4
.52600	.68000	.00000	262.50001	.00000	
.54000	.62000	-23.00000	126.69291	-99.70158	
.55000	.54000	-46.00000	65.43615	-71.75546	
.57000	.50000	-101.00000	26.03095	-34.07171	
.60000	.65000	-180.00000	10.60606	-.00937	
.70000	.38000	107.00000	4.92882	36.77423	
.80000	.88000	74.00000	8.75093	65.62201	
.90300	.36000	.00000	106.25000	.00000	
.40000	.94000	99.00000	2.67304	42.64275	
.50000	.80000	43.00000	38.31975	116.13944	
.51000	.75000	35.00000	65.55167	128.89643	
.52000	.70000	18.00000	160.87933	136.45454	5
.52900	.60000	.00000	200.00000	.00000	
.54000	.53000	-25.00000	112.29294	-69.94658	

t = 1.27 cm.

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.55000	.42000	-59.00000	55.37363	-48.40586	
.56000	.43000	-96.00000	31.97435	-33.55160	
.58000	.53000	-163.00000	15.67027	-6.76135	5
.60000	.70000	1629.99998	8.88630	-4.15048	
.70000	.90000	103.00000	4.28987	39.60133	
.85000	.83000	59.00000	18.65659	85.32422	
.90000	.31000	35.00000	76.83630	30.22607	
.40000	.95000	105.00000	2.03648	38.33537	
.45000	.93000	86.00000	3.89381	53.47704	
.50000	.81000	49.00000	28.98912	103.05221	
.52000	.66000	25.00000	117.95524	116.57397	
.53000	.53000	.00000	162.76596	.00000	
.54000	.30000	-40.00000	72.18330	-30.58926	6
.55000	.37000	-76.00000	45.05832	-37.48278	
.56000	.40000	-145.00000	23.13825	-12.64528	
.57000	.46000	-171.00000	18.59241	-3.40197	
.60000	.75000	139.00000	8.11909	18.26902	
.65000	.88000	105.00000	5.05936	38.12759	
.70000	.92000	87.00000	4.38919	52.50627	
.40000	.95000	109.00000	1.93402	35.63824	
.50000	.82000	64.00000	17.18304	77.30909	
.51000	.74000	57.00000	30.51067	83.70420	
.52000	.63000	41.00000	67.62848	92.68492	
.53000	.37000	15.00000	102.23672	22.68405	
.53500	.25000	.00000	83.33333	.00000	
.54000	.21000	-121.00000	37.92288	-14.28475	7
.55000	.18000	-140.00000	36.98479	-8.84821	
.56000	.41000	174.00000	20.96971	2.16838	
.60000	.84000	125.00000	5.51552	25.78727	
.70000	.93000	90.00000	3.62289	49.87839	
.80000	.92000	76.00000	5.48193	63.71561	

t=1.27cm

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.40000	.94000	115.00000	2.17351	31.81949	
.50000	.87000	79.00000	8.53223	59.94582	
.52000	.66000	63.00000	33.74908	70.32332	
.53000	.38000	57.00000	58.57104	43.62968	
.54000	.18000	75.00000	51.51367	18.51202	8
.55000	.30000	144.00000	28.88340	11.19862	
.56000	.60000	134.00000	14.58964	19.68350	
.60000	.91000	111.00000	3.46584	34.26069	
.80000	.92000	73.00000	5.87086	67.25174	
1.00000	.90000	44.00000	18.44416	121.36843	
1.13400	.53000	.00000	162.76596	.00000	
.40000	.95000	119.00000	1.72676	29.43491	
.50000	.90000	87.00000	5.53789	52.39182	
.53000	.55000	80.00000	31.38222	48.73829	
.54000	.51000	111.00000	22.76049	29.29549	
.55000	.63000	120.00000	14.87950	26.92562	
.57000	.68000	102.00000	5.27117	40.22589	9
.60000	.94000	93.00000	2.93701	47.37165	
.70000	.96000	69.00000	3.17856	72.66778	
.80000	.93000	51.00000	9.73058	104.10216	
.90000	.92000	36.00000	21.46908	151.15125	
1.00000	.80000	12.00000	240.14367	221.87789	
1.04500	.83000	.00000	538.23534	.00000	
1.10000	.72000	-19.00000	153.53832	-149.44535	
1.15000	.48000	-48.00000	65.44664	-60.66330	
1.20000	.07000	175.00000	43.47835	.53545	
.40000	.95000	120.00000	1.70929	28.85093	
.50000	.96000	100.00000	1.73867	41.93450	
.52000	.90000	99.00000	4.54285	42.50912	10
.53000	.81000	103.00000	8.51168	39.07009	
.54000	.65000	105.00000	6.41732	37.97610	

t=1.27cm

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10

.55000	.90000	103.00000	4.28987	39.60133
.60000	1.00000	92.00000	.00000	48.29414
.80000	.93000	67.00000	5.93643	75.22840
1.00000	.90000	35.00000	28.32038	153.87281
1.10000	.70000	.00000	283.33334	.00000

Appendix IV

Data for 600 MHZ Circular Disc Grounded

t= .635 cm.

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FREQUENCY	REFLECTION MAG.	REFLECTION ANG.	R	X	
.40000	.98000	115.00000	.71011	31.85776	1
.50000	.96700	67.00000	1.07396	75.54314	
.52000	.90000	54.00000	12.63609	96.83938	
.53000	.88000	35.00000	33.91305	151.73450	
.54000	.82000	18.00000	145.40947	224.91711	
.55100	.80000	.00000	450.00002	.00000	
.57000	.78000	-42.00000	43.60817	-116.22953	
.60000	.79000	-135.00000	6.85699	-20.38595	
.62000	.90000	-170.00000	2.65175	-4.37154	
.70000	.95000	125.00000	1.62942	26.01526	
.80000	.94000	90.00000	3.09043	49.91422	
.92000	.72000	.00000	307.14289	.00000	
.40000	.96000	120.00000	1.36056	28.86020	2
.50000	.95000	70.00000	3.89256	71.27644	
.52000	.9[illegible]000	55.00000	12.22045	94.82746	
.53000	.89000	37.00000	30.59265	143.61744	
.54000	.80000	22.00000	115.03284	191.49751	
.55100	.76000	.00000	404.54552	.00000	
.57600	.76000	-42.00000	47.15058	-113.52025	
.60000	.79000	-130.00000	7.12104	-22.93430	
.62500	.90000	-170.00000	2.65175	-4.37154	
.70000	.95000	137.00000	1.48100	19.68919	
.80000	.95000	100.00000	2.18412	41.91727	
.92000	.7[illegible]000	.00000	283.33334	.00000	
.40000	.98000	122.00000	.66031	27.72045	3
.50000	.95000	74.00000	3.53647	66.24303	
.52000	.90000	60.00000	10.44190	85.66360	
.53000	.89000	45.00000	19.49088	117.98840	
.54000	.80000	25.00000	94.80138	178.04491	

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t = .635cm.

.55000	.78000	5.00000	360.35849	125.10035	
.55500	.77000	.00000	384.78265	.00000	
.57000	.75000	-43.00000	47.00526	-109.90040	3
.60000	.78000	-134.00000	7.27411	-20.85059	
.70000	.95000	140.00000	1.45193	18.19360	
.80000	.94000	105.00000	2.45594	38.31715	
.92300	.58000	.00000	188.09524	.00000	
.40000	.98000	127.00000	.63067	24.93455	
.50000	.97000	84.00000	1.70046	55.51209	
.52000	.98000	67.00000	8.58608	74.87090	
.53000	.84000	50.00000	23.53030	102.85209	
.54000	.73000	28.00000	95.81356	140.58188	
.55000	.70000	9.00000	237.80210	102.10621	
.55500	.69000	.00000	272.58065	.00000	4
.57000	.68000	-55.00000	39.40180	-81.64389	
.60000	.82000	-150.00000	5.29683	-13.26577	
.70000	.95000	140.00000	1.45193	18.19360	
.80000	.94000	111.00000	2.27619	34.32457	
.92500	.52000	.00000	158.33333	.00000	
.40000	.98000	132.00000	.60523	22.26734	
.50000	.96000	94.00000	1.90741	46.59903	
.52000	.90000	78.00000	6.61809	61.32539	
.53000	.82000	62.00000	18.15420	80.23810	
.54000	.73000	45.00000	38.75654	109.16143	
.55000	.68000	19.00000	152.31499	125.43303	5
.55600	.62000	.00000	213.15789	.00000	
.57000	.59000	-53.00000	51.10141	-73.86602	
.60000	.86000	-160.00000	5.72644	-8.71304	
.70000	.95000	137.00000	1.48100	19.68919	
.80000	.94000	115.00000	2.17351	31.81949	
.93000	.24000	.00000	81.57895	.00000	

t=.635cm.

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.40000	.96000	134.00000	.59611	21.22981	
.50000	.97000	103.00000	1.24323	39.76591	
.52000	.96000	92.00000	5.07354	48.03622	
.54000	.72000	58.00000	31.88721	80.84974	
.55000	.64000	40.00000	68.81258	95.88569	
.56000	.57000	.00000	182.55815	.00000	6
.58000	.60000	-125.00000	19.62482	-24.00290	
.60000	.82000	-173.00000	4.96349	-3.03748	
.70000	.95000	135.00000	1.50203	20.70334	
.80000	.94000	105.00000	2.45594	38.31715	
.93500	.20000	135.00000	36.28778	10.69454	
.40000	.98000	137.00000	.58348	19.70183	
.50000	.97000	110.00000	1.13480	35.00721	
.52000	.96000	100.00000	4.47653	41.76653	
.54000	.78000	75.00000	16.25712	62.55328	
.55000	.68000	52.00000	43.00946	85.73087	7
.56500	.40000	.00000	116.66667	.00000	
.58000	.58000	-152.00000	14.05671	-11.54291	
.59000	.73000	-178.00000	7.80584	-.86096	
.70000	.96000	128.00000	.62526	24.39219	
.80000	.94000	110.00000	2.30388	34.96941	
.40000	.99000	140.00000	.28457	18.20664	
.50000	.98000	120.00000	.67348	28.87231	
.52000	.94000	115.00000	2.17351	31.81949	
.54000	.78000	101.00000	10.27431	40.17905	
.56000	.44000	70.00000	45.17667	46.32421	8
.57000	.01000	180.00000	49.00990	.00038	
.57500	.40000	-165.00000	21.73164	-5.36392	
.60000	.90000	162.00000	2.69756	7.90577	
.70000	.94000	125.00000	1.96522	26.00537	
.60000	.95000	110.00000	1.91033	34.98501	

$t = .635$ cm.

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.40000	.95000	145.00000	1.40955	15.76223	
.50000	.98000	129.00000	.62002	23.85443	
.52000	.97000	127.00000	.95078	24.93051	
.55000	.89000	110.00000	4.33036	34.84280	
.56000	.64000	99.00000	18.34038	39.27415	9
.57000	.30000	137.00000	29.76405	13.38827	
.59000	.90000	145.00000	2.89268	15.72560	
.60000	.94000	140.00000	1.75122	18.18744	
.70000	.95000	120.00000	1.70929	28.85093	
.80000	.93000	110.00000	2.70131	34.95070	
.40000	.99000	145.00000	.27626	15.77320	
.50000	1.00000	135.00000	.00000	20.71930	
.52000	.99000	137.00000	.29028	19.70358	
.55000	.90000	130.00000	3.20229	23.24539	
.56500	.89000	131.00000	3.51242	22.70174	
.57000	.85000	138.00000	4.64746	19.05712	10
.60000	1.00000	133.00000	.00000	21.74924	
.70000	1.00000	123.00000	.00000	27.15647	
.80000	.98000	113.00000	.72640	33.09828	

t= .953 cm.

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FREQUENCY	REFLECTION MAG.	REFLECTION ANG.	R	X	
.40000	.95000	89.00000	2.60839	50.82218	
.48000	.92000	53.00000	10.39396	99.43025	
.51000	.85000	34.00000	44.31979	151.80898	
.52000	.83000	22.00000	103.87663	207.61069	
.53000	.79000	8.00000	316.02789	184.84662	
.53600	.75000	.00000	350.00000	.00000	1
.55000	.70000	-24.00000	120.84934	-134.91628	
.56000	.67000	-42.00000	60.82731	-98.95544	
.57000	.63000	-67.00000	33.34221	-64.11722	
.59000	.63000	-130.00000	13.66620	-21.87693	
.62000	.78000	169.00000	6.23641	4.74939	
.65000	.86000	135.00000	4.40540	20.58190	
.75000	.92000	82.00000	4.83020	57.29725	
.89000	.74000	20.00000	144.23000	161.35942	
.90300	.67000	.00000	253.03031	.00000	
.40000	.95000	97.00000	2.28461	44.19385	
.50000	.90000	47.00000	16.31551	113.03307	
.51000	.86000	39.00000	32.32238	134.34360	
.52000	.81000	26.00000	85.96926	177.50781	
.53000	.78000	10.00000	271.58994	187.85038	
.53700	.74000	.00000	334.61539	.00000	2
.55000	.70000	-22.00000	132.86964	-136.61784	
.57000	.67000	-65.00000	31.22665	-68.80924	
.59000	.64000	-125.00000	13.77192	-24.46277	
.62000	.80000	180.00000	5.55556	.00970	
.70000	.61000	115.00000	3.69606	31.73837	
.80000	.92000	78.00000	5.24756	61.48554	
.90500	.64000	.00000	227.77779	.00000	
.40000	.95000	102.00000	2.12222	40.45434	3

t = .953 cm.

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.50000	.89000	49.00000	16.65408	107.60333	
.52000	.81000	28.00000	76.19248	168.48232	
.53000	.74000	10.00000	251.11316	142.63466	
.53700	.71000	.00000	294.82761	.00000	
.55000	.64000	-26.00000	113.92766	-108.26404	3
.57000	.62000	-71.00000	31.39170	-59.78398	
.59000	.66000	-131.00000	12.26256	-21.64990	
.62000	.79000	179.00000	5.86638	.43997	
.70000	.91000	122.00000	3.07828	27.64372	
.65000	.86000	61.00000	14.37836	83.05851	
.90000	.61000	17.00000	152.85185	86.82058	
.90800	.57000	.00000	182.55815	.00000	
.40000	.94000	109.00000	2.33244	35.62216	
.50000	.84000	57.00000	12.63896	90.74719	
.52000	.79000	34.00000	59.82714	140.60373	
.53000	.71000	16.00000	178.25982	140.68018	
.53900	.66000	.00000	244.11765	.00000	4
.55000	.60000	-28.00000	106.51453	-93.74962	
.57000	.59000	-83.00000	27.07041	-48.63366	
.59000	.67000	-143.00000	10.93965	-16.01476	
.62000	.81000	173.00000	5.26816	3.03367	
.79000	.90000	124.00000	3.37341	26.49971	
.80000	.90000	92.00000	5.07354	48.03622	
.90000	.56000	26.00000	111.81964	79.97427	
.91200	.40000	.00000	116.66667	.00000	
.40000	.95000	115.00000	1.80219	31.83288	
.50000	.83000	63.00000	11.56732	80.40012	
.52000	.77000	39.00000	51.39986	122.35105	
.53000	.66000	18.00000	156.61300	113.17346	5
.53900	.60000	.00000	200.00000	.00000	
.54000	.51000	-35.00000	87.14543	-68.89944	

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t=.953cm

102

.57000	.54000	-114.00000	20.46653	-28.50806	
.59000	.57000	-164.00000	13.94474	-6.49870	
.62000	.83000	160.00000	4.78823	8.74683	5
.70000	.92000	121.00000	2.74909	28.23252	
.85000	.89000	77.00000	7.47092	62.32272	
.92500	.10000	9.00000	60.92595	1.92520	
.40000	.95000	120.00000	1.70929	28.85093	
.50000	.90000	74.00000	7.23218	65.85817	
.52000	.77000	53.00000	30.56478	92.33187	
.53000	.62000	31.00000	95.74785	99.32134	
.54100	.52000	.00000	158.33333	.00000	
.55000	.37000	-43.00000	72.45015	-42.35937	
.56000	.39000	-96.00000	34.37052	-31.44561	6
.58000	.63000	-169.00000	11.44984	-4.57301	
.60000	.83000	163.00000	5.67838	7.38723	
.70000	.93000	116.00000	2.52067	31.19512	
.80000	.91000	96.00000	4.25925	44.84894	
.90000	.62000	65.00000	35.78263	65.31941	
.92000	.78000	90.00000	37.38691	33.20950	
.40000	.95000	123.00000	1.65992	27.13335	
.50000	.90000	83.00000	5.97367	56.16960	
.52000	.76000	65.00000	22.58763	73.66096	
.53000	.58000	44.00000	66.11030	80.26919	
.54000	.38000	10.00000	108.04579	16.66354	
.54100	.35000	.00000	103.84615	.00000	
.55000	.18000	-60.00000	56.76011	-18.28722	7
.56000	.36000	-147.00000	25.10793	-11.31743	
.57000	.56000	-176.00000	14.11857	-1.61582	
.60000	.86000	144.00000	4.15869	16.15291	
.80000	.92000	91.00000	4.08914	48.97715	
.90000	.74000	72.00000	20.75165	64.56184	

t=.953cm.

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.40000	.95000	129.00000	1.57370	23.83816	
.50000	.94000	98.00000	2.71348	43.40075	
.52000	.81000	84.00000	11.56769	54.19201	
.53000	.60000	70.00000	33.70537	59.38299	
.54000	.32000	52.00000	63.36124	35.59709	8
.54500	.02000	90.00000	49.96041	1.99922	
.55000	.16000	173.00000	36.27159	1.45615	
.56000	.50000	164.00000	16.95940	6.24064	
.57000	.73000	147.00000	8.47085	14.42756	
.60000	.93000	128.00000	2.24447	24.35555	
.70000	.95000	102.00000	1.68938	40.47049	
1.15000	.44000	.00000	128.57143	.00000	
.40000	.96000	132.00000	1.22274	22.25895	
.50000	.96000	109.00000	1.53951	35.65121	
.52000	.88000	102.00000	5.27117	40.22589	
.53000	.71000	96.00000	15.00695	42.73764	
.54000	.50000	100.00000	26.34475	34.59402	9
.56000	.75000	132.00000	8.52536	21.72760	
.59000	.96000	120.00000	1.36056	28.86020	
.70000	.97000	97.00000	1.35742	44.22740	
1.10000	.76000	26.00000	99.90764	157.58316	
1.14100	.62000	.00000	213.15789	.00000	
.40000	.95000	132.00000	1.53619	22.25252	
.50000	.97000	115.00000	1.07052	31.85194	
.51000	.96000	114.00000	1.45072	32.45999	
.54000	.81000	114.00000	7.42878	31.97266	
.55000	.85000	118.00000	5.50548	29.78349	
.58000	.95000	110.00000	1.52065	34.99758	10
.80000	.95000	82.00000	2.97667	57.44099	
1.10000	.77000	21.00000	131.18644	177.82216	
1.13200	.71000	.00000	294.82761	.00000	

$t = 1.27\ cm$

. E7374				DATE 072176	PAGE 1
FREQUENCY	REFLECTION MAG.	REFLECTION ANG.	R	X	
.40000	.90000	78.00000	6.61809	61.32539	
.50000	.84000	25.00000	80.45296	194.00398	
.51000	.80000	19.00000	141.56655	204.81782	
.52000	.79000	7.00000	336.38103	172.28866	
.52500	.78000	.00000	404.54552	.00000	1
.54000	.72000	-22.00000	131.42000	-147.18423	
.56000	.58000	-63.00000	40.98174	-63.82523	
.58000	.56000	-120.00000	18.32016	-25.89204	
.60000	.64000	-170.00000	11.05588	-4.17100	
.70000	.90000	85.00000	5.74787	54.24538	
.80000	.89000	52.00000	16.33177	100.39229	
.88900	.64000	.00000	227.77779	.00000	
.40000	.92000	82.00000	4.83020	57.29725	
.50000	.84000	27.00000	78.54399	182.73766	
.51000	.80000	18.00000	152.16821	208.96389	
.52000	.78000	8.00000	307.96807	170.72179	
.52500	.77000	.00000	384.78265	.00000	2
.55000	.70000	-40.00000	61.08381	-107.77208	
.57000	.59000	-829.99999	19.16624	-31.50357	
.63000	.64000	-163.00000	11.20926	-7.11346	
.70000	.90000	97.00000	4.68214	44.02763	
.80000	.90000	59.00000	10.76203	87.38667	
.89000	.62000	.00000	213.15789	.00000	
.40000	.96000	90.00000	5.24964	49.73347	
.50000	.84000	30.00000	58.73379	167.56382	
.51000	.80000	22.00000	115.03284	191.49751	3
.52000	.76000	8.00000	291.75767	146.09768	
.52500	.75000	.00000	350.00000	.00000	
.54000	.64000	-28.00000	105.65862	-107.52957	

$t = 1.27$ cm.

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.56000	.58000	-70.00000	35.31703	-58.00927	
.58000	.59000	-125.00000	16.09903	-23.87526	
.60000	.64000	-168.00000	11.09136	-5.00813	3
.70000	.9[illegible]000	105.00000	4.17495	38.20680	
.80000	.88000	67.00000	10.38219	74.55238	
.89000	.58000	.00000	188.09524	.00000	
.40000	.95000	95.00000	2.35769	45.77068	
.50000	.84000	38.00000	38.56875	135.48863	
.52000	.74000	17.00000	171.03594	163.57206	
.52900	.73000	.00000	283.33334	.00000	
.55000	.60000	-40.00000	72.61515	-87.50863	4
.57000	.53000	-95.00000	26.18592	-38.45355	
.58000	.54000	-135.00000	17.23559	-18.58592	
.60000	.69000	-175.00000	9.18864	-2.11870	
.70000	.90000	105.00000	4.17495	38.20680	
.80000	.88000	73.00000	8.95552	66.80973	
.90000	.41000	.00000	119.49152	.00000	
.40000	.92000	103.00000	3.39837	39.66831	
.50000	.84000	46.00000	27.33759	112.20798	
.52000	.70000	25.00000	115.31322	133.76251	
.53000	.62000	4.00000	208.79147	29.33365	
.53100	.62000	.00000	213.15789	.00000	5
.55000	.50000	-48.00000	64.56705	-63.97086	
.57000	.44000	-120.00000	24.68470	-23.33223	
.60000	.72000	164.00000	8.29637	6.84611	
.70000	.90000	105.00000	4.17495	38.20680	
.80000	.87000	77.00000	8.90346	62.09118	
.40000	.94000	107.00000	2.39227	36.95232	
.50000	.84000	57.00000	18.62275	89.11925	6
.52000	.69000	35.00000	75.79356	114.50041	
.53000	.56000	8.00000	167.82639	38.10679	

t= 1.27 cm.

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.53400	.48000	.00000	142.30769	.00000	
.54000	.40000	-15.00000	108.45635	-26.73061	
.56000	.32000	-128.00000	29.99434	-16.85634	
.57000	.44000	-160.00000	19.95620	-7.45552	
.60000	.78000	145.00000	6.78449	15.50910	6
.76000	.90000	97.00000	4.68214	44.02763	
.80000	.89000	76.00000	7.31156	61.23001	
.40000	.96000	109.00000	1.53951	35.65121	
.50000	.86000	67.00000	12.19888	74.16629	
.52000	.66000	46.00000	54.42039	91.54625	
.53000	.44000	24.00000	103.47449	45.92273	
.54000	.28000	.00000	88.88889	.00000	
.55000	.17000	-90.00000	47.19424	-16.52357	
.56000	.32000	-179.00000	25.75908	-.32771	7
.57000	.50000	160.00000	17.12663	7.81769	
.60000	.82000	127.00000	6.16018	24.63386	
.70000	.96000	90.00000	5.24964	49.73347	
.80000	.90000	75.00000	7.06929	64.68734	
.40000	.98000	115.00000	.71011	31.85776	
.50000	.90000	80.00000	6.34550	59.20015	
.52000	.70000	68.00000	26.41507	67.22787	
.53000	.44000	57.00000	56.45273	51.66226	
.54000	.24000	60.00000	57.63593	25.42126	
.54500	.10000	105.00000	46.62248	9.09831	8
.56000	.52000	140.00000	17.64977	16.17757	
.58000	.80000	120.00000	7.37815	28.40279	
.60000	.90000	112.00000	3.82466	33.59850	
.70000	.95000	87.00000	2.70427	52.62594	
.60000	.96000	75.00000	2.75211	65.09910	
1.24900	.53000	.00000	188.09524	.00000	
.40000	.95000	120.00000	1.36056	28.86020	9

t=1.27cm

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.50000	.95000	95.00000	2.35769	45.77068	
.52000	.80000	89.00000	11.16788	49.62728	
.53000	.62000	88.00000	22.95496	46.20958	
.54000	.53000	97.00000	25.50255	37.31318	
.55000	.6[illegible]000	120.00000	16.32860	26.51867	9
.57000	.83000	111.00000	6.81216	33.93792	
.60000	.99000	105.00000	.39926	38.37391	
.70000	.96000	85.00000	1.10663	54.56338	
.80000	.98000	75.00000	1.36288	65.15436	
1.249[illegible]	.58000	.00000	188.09524	.00000	
.40000	.98000	125.00000	.64199	26.03364	
.50000	.99000	108.00000	.38395	36.33472	
.52000	.94000	108.00000	2.36189	36.28304	
.53000	.87000	108.00000	5.29814	36.06846	
.54000	.84000	110.00000	6.45666	34.62609	
.55000	.9[illegible]000	112.00000	3.82466	33.59850	10
.57000	.96000	105.00000	.80251	38.36923	
.60000	1.[illegible]000	104.00000	.00000	39.07342	
.70000	1.[illegible]000	90.00000	.00000	50.00982	
.80000	.98000	82.00000	1.17349	57.51517	

Appendix V

Data for 1 GHZ Circular Disc Ungrounded

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t= .635 cm.

1

FREQUENCY	REFLECTION MAG.	REFLECTION ANG.	R	X
.70000	.92000	84.00000	4.64404	55.32591
.75000	.92000	71.00000	6.15836	69.74910
.80000	.91000	53.00000	11.73173	99.19009
.85000	.85000	29.00000	58.89361	174.89432
.86000	.83000	23.00000	96.71739	201.62264
.87000	.83000	19.00000	130.36727	226.44683
.88000	.81000	12.00000	240.51624	235.53347
.89000	.74000	.00000	334.61539	.00000
.90000	.75000	-12.00000	229.60955	-163.65472
.91000	.72000	-23.00000	124.86727	-145.86506
.92000	.67000	-30.00000	99.77232	-93.52594
.94000	.59000	-70.00000	34.51592	-58.70595
.95000	.58000	-85.00000	26.86455	-46.78087
1.00000	.67000	-158.00000	10.23911	-9.33431
1.05000	.76000	161.00000	7.00587	8.21611
1.20000	.88000	104.00000	5.12775	38.81764
1.40000	.85000	35.00000	42.06240	147.78280
1.45000	.77000	11.00000	250.71720	180.94599
1.46000	.73000	.00000	320.37039	.00000

2

FREQUENCY	REFLECTION MAG.	REFLECTION ANG.	R	X
.70000	.95000	90.00000	2.56292	49.94409
.75000	.95000	75.00000	3.45636	65.05679
.80000	.97000	56.00000	8.19173	93.49132
.85000	.87000	29.00000	65.63835	169.78033
.86000	.81000	23.00000	104.30671	191.96487
.87500	.81000	19.00000	138.29235	212.06579
.88000	.75000	9.00000	270.18551	144.89515
.88900	[illegible]	.00000	253.33334	.00000
.90000	.67000	-18.00000	157.93727	-118.65577
[illegible]	.62000	-41.00000	68.63070	-90.68589

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t= .635 cm.

.95000	.59000	-93.00000	23.12330	-41.79841	
1.00000	.69000	-161.00000	9.42009	-8.08669	
1.05000	.79000	164.00000	5.98046	6.93743	2
1.10000	.85000	144.00000	4.47940	16.13660	
1.20000	.96000	111.00000	3.87020	34.23293	
1.35000	.86000	64.00000	13.21310	78.43732	
1.40000	.82000	43.00000	34.63917	118.25162	
1.46500	.70000	.00000	283.33334	.00000	
.70000	.90000	95.00000	4.83090	45.59306	
.80000	.90000	61.00000	10.13730	83.99016	
.85000	.86000	33.00000	60.38965	146.16405	
.86000	.76000	26.00000	99.90764	157.58316	
.87000	.76000	20.00000	141.51273	174.14651	
.88000	.71000	10.00000	234.65092	116.66296	
.88800	.66000	.00000	244.11765	.00000	3
.89000	.63000	-4.00000	215.44129	-31.39355	
.90000	.60000	-21.00000	133.50924	-89.69948	
.92000	.54000	-51.00000	57.89090	-68.58339	
.95000	.54000	-112.00000	20.88529	-29.52531	
1.00000	.71000	-175.00000	8.49537	-2.12943	
1.05000	.80000	158.00000	5.76316	9.60337	
1.20000	.93000	114.00000	3.73763	32.35143	
1.40000	.80000	52.00000	27.48937	96.26665	
1.47200	.61000	.00000	206.41026	.00000	
.70000	.95000	102.00000	2.12222	40.45434	
.80000	.90000	71.00000	7.76325	69.53598	
.85000	.83000	43.00000	38.31975	116.13944	
.86000	.74000	34.00000	70.56335	129.07205	
.87000	.72000	28.00000	97.52377	136.88185	4
.88000	.67000	15.00000	178.29407	112.19008	
.89000	.58000	.00000	188.09524	.00000	

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t= .635 cm

.90000	.53000	-21.00000	123.43482	-65.19760	
.91000	.53000	-41.00000	74.77451	-72.30501	
.93000	.44000	-89.00000	34.22544	-37.34337	
.95000	.52000	-131.00000	18.68396	-20.10505	
1.00000	.73000	174.00000	7.82453	2.56567	4
1.10000	.86000	137.00000	4.34409	19.57530	
1.30000	.89000	93.00000	5.51489	47.15322	
1.40000	.84000	60.00000	17.00929	84.05342	
1.51000	.20000	.00000	75.00000	.00000	
.70000	.95000	110.00000	1.91033	34.98501	
.80000	.92000	81.00000	4.92864	58.31246	
.85000	.81000	55.00000	23.66023	91.29139	
.86000	.75000	47.00000	40.55507	101.68205	
.88000	.61000	26.00000	113.92766	108.26404	
.89000	.52000	12.00000	144.12089	42.70718	
.89400	.51000	.00000	154.08163	.00000	5
.90000	.46000	-15.00000	122.06585	-36.86197	
.91000	.42000	-41.00000	75.92257	-50.79630	
.92000	.34000	-73.00000	48.23911	-35.46783	
.95000	.52000	-155.00000	16.48582	-9.93853	
1.00000	.77000	159.00000	6.71689	9.11400	
1.10000	.89000	131.00000	3.51242	22.70174	
1.30000	.90000	95.00000	4.83090	45.59306	
.70000	.95000	117.00000	1.76333	30.62110	
.80000	.91000	91.00000	4.62221	48.93055	
.85000	.74000	66.00000	23.92549	71.49938	
.86000	.67000	59.00000	36.32344	75.69955	
.87000	.61000	49.00000	54.92385	80.53225	6
.88000	.46000	37.00000	82.67433	58.05350	
.89000	.25000	21.00000	82.93949	18.05861	
.894[illegible]	.23000	.00000	79.87013	.00000	

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t= .635 cm.

.90000	.13000	-59.00000	55.67061	-12.61925	6
.91000	.22000	-127.00000	36.23483	-13.38332	
.93000	.51000	175.00000	16.25308	1.96133	
1.00000	.84000	137.00000	5.01716	19.53223	
1.20000	.96000	104.00000	4.23151	38.89937	
.70000	.96000	122.00000	3.43773	27.62383	
.80000	.94000	103.00000	2.52375	39.71887	7
.83000	.85000	86.00000	8.65243	52.87606	
.85000	.84000	83.00000	9.80969	55.56070	
.87000	.76000	71.00000	24.66152	64.00657	
.89000	.36000	66.00000	52.01667	39.30596	
.90000	.1[illegible]000	90.00000	49.01181	9.90137	
.91000	.25000	162.00000	30.47842	5.02858	
.94000	.71000	142.00000	9.45362	16.67272	
1.00000	.87000	123.00000	4.49489	26.98675	
1.20000	.93000	97.00000	3.23022	44.14202	
.70000	.95000	125.00000	1.62942	26.01526	8
.80000	.99000	110.00000	3.91715	34.87492	
.83000	.90000	105.00000	4.17495	38.20680	
.85000	.89000	98.00000	5.09696	43.21579	
.86000	.84000	92.00000	8.34517	47.59323	
.87000	.79000	89.00000	11.77470	49.48426	
.88000	.70000	89.00000	17.40264	47.76452	
.89000	.55000	94.00000	25.28994	39.78718	
.89500	.41000	110.00000	28.71846	26.60281	
.91000	.59000	130.00000	15.47476	21.46260	
.93000	.80000	124.00000	7.10241	26.17441	
.95000	.84000	122.00000	5.67139	27.45070	
1.00000	.99000	114.00000	3.73763	32.35143	
1.20000	.95000	93.00000	2.43561	47.39859	
.70000	.95000	128.00000	1.58700	24.37542	9

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t=.635 cm.

9

.81000	.95000	117.00000	1.76333	30.62110
.87000	.90000	105.00000	4.17495	38.20680
.89000	.87000	110.00000	[illegible].16877	34.76765
.90000	.86000	111.00000	5.52725	34.08696
.93000	.95000	109.00000	1.93402	35.63824
.95000	.93000	109.00000	2.73478	35.60286
1.00000	.93000	105.00000	2.87950	38.29529
1.10000	.96000	99.00000	1.76454	42.68261
1.20000	.93000	87.00000	3.82243	52.55290

t = .953 cm.

FREQUENCY	REFLECTION MAG.	REFLECTION ANG.	R	X	
0.70000	0.93000	59.99994	7.22702	86.16156	
0.80000	0.87000	26.99998	58.86121	191.24470	
0.81000	0.84000	23.99998	86.17825	200.00040	
0.82000	0.81000	21.99998	111.63170	196.96730	
0.83000	0.80000	16.99998	163.79090	212.80880	
0.84000	0.79000	8.99999	295.75920	194.44710	1
0.85100	0.77000	0.00000	384.78290	0.00000	
0.88000	0.67000	-16.99998	164.56820	-116.97750	
0.90000	0.59000	-40.99998	71.24995	-84.60258	
0.95000	0.47000	-116.99980	23.64586	-25.42303	
1.00000	0.58000	171.99990	13.35185	3.25692	
1.10000	0.78000	110.99990	9.03512	33.60529	
1.20000	0.82000	72.99995	13.73402	65.74640	
1.40000	0.72000	0.00000	307.14110	0.00000	
0.70000	0.92000	66.99995	6.81331	75.12479	
0.80000	0.82000	31.99998	58.17979	154.32380	
0.81000	0.81000	28.99998	71.89545	164.17440	
0.82000	0.80000	25.99998	89.15729	173.68620	
0.83000	0.79000	20.99998	126.12600	189.96200	
0.84000	0.78000	11.99999	237.38570	196.59000	
0.85000	0.75000	5.00000	320.71630	95.82437	
0.86000	0.71000	0.00000	294.82440	0.00000	2
0.87000	0.70000	-5.00000	267.50170	-63.99202	
0.90000	0.58000	-43.99998	66.11028	-80.26913	
0.91000	0.54000	-56.99998	50.36420	-64.39070	
0.95000	0.50000	-119.99980	21.43137	-24.75056	
0.98000	0.52000	-169.99980	15.89867	-3.94360	
1.00000	0.66000	171.99990	12.55760	3.28566	
1.10000	0.78000	118.99980	8.28137	28.85794	
1.20000	0.82000	83.99985	10.91512	54.34174	
1.41000	0.69000	0.00000	272.57810	0.00000	
0.70000	0.92000	71.99994	6.01159	68.48564	
0.80000	0.85000	36.99998	38.04105	140.23430	
0.81000	0.81000	31.99998	60.93149	152.08470	
0.82000	0.78000	29.99998	76.08304	151.52700	3
0.83000	0.76000	24.99998	105.61150	160.59350	
0.84000	0.74000	13.99999	202.77480	160.46290	
0.85000	0.71000	5.00000	277.02880	69.12903	

t = .953 cm.

0.86000	0.67000	0.00000	253.02840	0.00000	3
0.87000	0.65000	-6.99999	218.43710	-59.91801	
0.90000	0.47000	-50.99998	61.90628	-58.04071	
0.95000	0.45000	-139.99980	21.07823	-15.29580	
1.00000	0.61000	160.99980	12.43125	7.87171	
1.10000	0.79000	118.99980	7.86488	28.91736	
1.20000	0.83000	88.99986	9.37273	50.00409	
1.40000	0.70000	20.99998	139.37060	137.09010	
1.44800	0.54000	0.00000	167.39120	0.00000	
0.70000	0.95000	79.99997	3.10068	59.50345	4
0.80000	0.82000	57.99997	20.39455	86.57640	
0.81000	0.80000	38.99998	45.39929	126.96730	
0.82000	0.76000	36.99998	58.08563	125.77790	
0.83000	0.72000	30.99998	84.77988	130.54460	
0.84000	0.70000	19.99998	146.20720	137.25430	
0.85000	0.66000	9.99999	208.03650	84.47775	
0.86000	0.61000	4.00000	202.45400	27.43631	
0.86700	0.60000	0.00000	199.99970	0.00000	
0.88000	0.47000	-19.99998	115.39660	-47.61317	
0.89000	0.41000	-37.99998	79.70079	-48.36166	
0.90000	0.38000	-61.99995	54.32309	-42.60208	
0.95000	0.46000	-165.99990	18.73404	-5.29638	
1.00000	0.67000	148.99980	10.60919	13.29326	
1.20000	0.85000	88.99986	8.19794	50.21376	
1.40000	0.71000	29.99998	90.39415	129.40610	
1.47200	0.35000	0.00000	103.84610	0.00000	
0.70000	0.93000	88.99986	3.68708	50.75421	5
0.80000	0.84000	52.99998	21.19829	96.60120	
0.81000	0.81000	48.99998	28.98907	103.05190	
0.83000	0.71000	40.99998	57.35201	107.73100	
0.85000	0.62000	19.99998	140.44320	96.74382	
0.86000	0.55000	10.99999	156.59660	47.11674	
0.87000	0.48000	0.00000	142.30770	0.00000	
0.88000	0.34000	-18.99998	93.55992	-23.41743	
0.89000	0.25000	-87.99989	44.85846	-23.90976	
0.93000	0.41000	179.99980	20.92198	0.00814	
1.00000	0.73000	131.99980	9.39658	21.62317	
1.20000	0.87000	86.99985	7.29811	52.16435	
1.40000	0.77000	39.99998	49.27315	119.79860	
0.70000	0.91000	96.99988	4.19368	44.07091	6

t= .953 cm.

0.80000	0.85000	65.99994	13.46013	75.32457	
0.84000	0.66000	45.99998	54.42036	91.54614	
0.86000	0.46000	28.99998	96.87370	54.79845	
0.87000	0.35000	19.99998	94.41479	25.75670	
0.88000	0.13000	9.99999	64.60542	2.96661	
0.89000	0.02000	179.99980	48.03923	0.00076	6
0.89500	0.13000	-159.99980	38.97519	-3.52885	
0.90000	0.21000	179.99980	32.64464	0.00566	
0.95000	0.66000	132.99980	12.08278	20.67276	
1.00000	0.80000	114.99980	7.77262	31.31204	
1.30000	0.88000	61.99975	11.89976	81.96234	
0.70000	0.93000	101.99980	3.00062	40.41032	
0.80000	0.96000	78.99995	6.47917	60.25175	
0.85000	0.50000	55.99998	54.29224	60.00880	
0.88000	0.26000	89.99983	43.67229	24.35605	
0.90000	0.45000	127.99980	22.70274	20.19377	7
0.95000	0.77000	110.99990	9.49201	33.52504	
1.00000	0.86000	100.99980	6.29772	40.83527	
1.20000	0.90000	71.99994	7.57879	68.28136	
1.40000	0.89000	39.99998	24.26234	133.51190	
1.73000	0.75000	0.00000	350.00000	0.00000	
0.70000	0.94000	107.99980	2.36189	36.28307	
0.80000	0.92000	88.99986	4.23391	50.71072	
0.84000	0.78000	81.99991	14.07609	55.52705	
0.87000	0.55000	87.99989	27.59320	43.48932	
0.88000	0.61000	101.99980	19.31425	36.70894	
0.89000	0.66000	106.99990	15.49499	34.65814	8
0.93000	0.80000	99.99988	9.38727	41.08893	
1.00000	0.91000	90.99989	4.62221	48.93059	
1.20000	0.96000	67.99995	3.26100	74.04117	
1.40000	0.90000	36.99998	25.51233	145.44020	
1.67300	0.80000	0.00000	449.99360	0.00000	
0.70000	0.93000	110.99990	2.66887	34.30644	
0.80000	0.94000	96.99988	2.75527	44.17033	
0.85000	0.89000	90.99989	5.70274	48.81847	
0.87000	0.84000	89.99983	8.63208	49.25909	
0.88000	0.88000	94.99985	5.85237	45.48378	9
0.91000	0.90000	90.99989	5.16009	48.87773	
1.00000	0.92000	85.99988	4.47109	53.42870	
1.30000	0.90000	48.99998	15.10456	107.98550	

E7373 DATE 072176 PAGE 1

t = 1.27 cm.

FREQUENCY	REFLECTION MAG.	REFLECTION ANG.	R	X	
.70000	.92000	45.00000	14.08668	119.31023	1
.75000	.90000	31.00000	35.57571	173.56529	
.80000	.82000	14.00000	201.96566	244.56789	
.81000	.80000	12.00000	240.14367	221.87789	
.82000	.76000	9.00000	289.63900	180.47520	
.83000	.75000	.00000	350.00000	.00000	
.85000	.71000	-11.00000	225.03494	-122.93892	
.86000	.57000	-30.00000	99.98704	-84.41142	
.90000	.49000	-54.00000	57.22336	-59.69851	
.95000	.33000	-138.00000	27.86006	-13.81197	
1.00000	.51000	145.00000	17.65492	13.96627	
1.10000	.73000	88.00000	15.76266	49.23850	
1.20000	.69000	51.00000	28.43831	98.21656	
1.30000	.77000	19.00000	144.39996	197.57931	
1.35000	.74000	.00000	334.61539	.00000	
.70000	.92000	51.00000	11.15807	103.86732	2
.80000	.82000	18.00000	145.40947	224.91711	
.81000	.79000	14.00000	206.49065	209.94576	
.82000	.76000	11.00000	246.96059	169.54795	
.83000	.73000	9.00000	257.01400	125.65459	
.84000	.71000	.00000	294.82761	.00000	
.85000	.67000	-9.00000	219.74822	-83.57538	
.88000	.55000	-29.00000	102.45763	-78.32753	
.90000	.45000	-59.00000	53.96781	-52.20097	
.95000	.33000	-150.00000	26.51501	-9.82484	
1.00000	.52000	145.00000	17.19028	14.06109	
1.10000	.74000	94.00000	13.70463	44.72533	
1.20000	.80000	60.00000	21.43320	82.49019	
1.35000	.71000	.00000	294.82761	.00000	

E7373					DATE 072176 PAGE 2
					t= 1.27 cm.
.70000	.91000	55.00000	10.96284	95.07070	
.80000	.80000	20.00000	131.89913	200.47443	
.81000	.77000	17.00000	169.37943	187.31085	
.82000	.72000	14.00000	198.73970	143.74164	
.83000	.69000	9.00000	231.63816	95.43757	
.84000	.67000	.00000	253.03031	.00000	3
.85000	.62000	-10.00000	188.56401	-65.94750	
.88000	.45000	-35.00000	85.71145	-55.47465	
.90000	.35000	-71.00000	49.04976	-36.99429	
.95000	.34000	-172.00000	24.71846	-2.65213	
1.00000	.57000	133.00000	16.05748	19.83622	
1.05000	.67000	111.00000	14.28601	32.43228	
1.20000	.86000	63.00000	19.70618	78.03156	
1.40000	.61000	.00000	206.41026	.00000	
[illegible]	.92000	62.00000	7.81797	82.68450	
.80000	.89000	27.00000	50.44628	196.06099	
.81000	.75000	23.00000	120.38193	161.25054	
.82000	.71000	20.00000	146.09762	143.06618	
.83000	.66000	14.00000	182.29987	103.13242	
.84000	.62000	6.00000	203.58334	42.85937	
.84300	.60000	.00000	200.00000	.00000	
.85000	.58000	-5.00000	183.50446	-27.95375	4
.87000	.47000	-19.00000	117.29906	-46.07006	
.90000	.26000	-88.00000	44.42740	-24.76192	
.92000	.19000	-150.00000	35.30440	-6.96300	
.95000	.38000	159.00000	23.07659	7.35251	
1.00000	.62000	123.00000	14.94557	25.25239	
1.20000	.81000	66.00000	17.24720	74.21705	
1.42500	.58000	.00000	188.09524	.00000	
.70000	.59200	70.00000	34.35454	58.84293	5

E7373					DATE 072176	PAGE 3
.81000	.74000	31.00000	81.09246	136.61867	t= 1.27cm.	
.82000	.67000	29.00000	99.52378	117.30673		
.83000	.68000	21.00000	133.50924	89.69948		
.84000	.56000	11.00000	160.24472	49.88497		
.85000	.46000	.00000	142.30769	.00000	5	
.87000	.32000	-15.00000	90.89524	-16.13450		
.90000	.13000	-170.00000	38.61554	-1.77713		
.93000	.42000	139.00000	22.74901	15.22719		
.95000	.54000	130.00000	19.81432	20.24302		
1.00000	.79000	107.00000	13.42806	35.25320		
1.20000	.82000	63.00000	17.65743	78.75496		
.70000	.92000	78.00000	5.24756	61.48554		
.80000	.78000	46.00000	37.32223	106.94032		
.85000	.39000	19.00000	102.25889	30.62250		
.87000	.18000	34.00000	65.91896	13.71295		
.88000	.17000	102.00000	44.16034	15.12420	6	
.90000	.34000	125.00000	29.37269	18.50339		
.95000	.66000	104.00000	16.08301	36.49917		
1.00000	.91000	93.00000	4.13021	43.30451		
1.11000	.85000	74.00000	11.06766	65.17233		
1.20000	.85000	57.00000	17.42135	89.50023		
1.63000	.85000	.00000	616.66685	.00000		
.70000	.91000	85.00000	5.14936	54.31074		
.80000	.86000	59.00000	22.06525	84.05397		
.83000	.58000	57.00000	47.09738	69.04062		
.85000	.39000	59.00000	56.50525	44.55237	7	
.87000	.41000	88.00000	36.50846	35.96405		
.90000	.64000	100.00000	18.09273	38.63099		
.95000	.80000	88.00000	11.36469	50.47860		
1.10000	.90000	67.00000	8.58608	74.87090		
1.40000	.64000	21.00000	97.29966	230.29054		

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t= 1.27 cm.

1.58000	.86000	.00000	783.33346	.00000	7
.70000	.92000	91.00000	4.08914	48.97715	
.80000	.88000	72.00000	9.16874	68.02482	
.82000	.78000	69.00000	18.66314	69.40540	
.86000	.63000	78.00000	26.57480	54.30501	
.89000	.78000	88.00000	12.60252	50.17320	8
.95000	.86000	79.00000	9.22673	59.82287	
1.00000	.89000	73.00000	8.17598	66.93919	
1.20000	.86000	49.00000	18.20547	107.18028	
1.51800	.87000	.00000	719.23100	.00000	
.70000	.94000	94.00000	2.88926	46.55199	
.75000	.93000	87.00000	3.82243	52.55290	
.80000	.93000	80.00000	4.38183	59.40881	
.83000	.87000	80.00000	8.35709	58.90574	9
.88000	.92000	79.00000	9.13712	60.40579	
.90000	.91000	75.00000	6.33494	64.78322	
1.00000	.92000	68.00000	7.49957	73.61591	
1.10000	.93000	58.00000	7.68443	89.71297	

Appendix VI

Data for 1 GHZ Circular Disc Grounded

E7375 DATE 072176 PAGE 1

t= .635 cm.

FREQUENCY	REFLECTION MAG.	REFLECTION ANG.	R	X	
.70000	.91000	94.00000	2.88926	46.55199	
.80000	.90000	62.00000	9.84725	82.36403	
.85000	.87000	35.00000	36.66675	150.51530	
.86000	.85000	30.00000	55.45538	169.84405	1
.87000	.82000	23.00000	100.65142	196.85502	
.88000	.78000	12.00000	237.38729	196.59152	
.89000	.77000	.00000	384.78265	.00000	
.90000	.75000	-14.00000	204.35268	-169.47885	
.95000	.60000	-80.00000	27.79187	-51.31651	
1.00000	.64000	-147.00000	11.88944	-14.04586	
1.02000	.72000	-175.00000	8.15477	-2.13439	
1.10000	.84000	142.00000	4.85947	17.07947	
.70000	.95000	97.00000	2.28481	44.19385	
.80000	.89000	67.00000	9.48138	74.71990	
.85000	.84000	40.00000	35.16894	128.98913	
.86000	.62000	34.00000	52.38074	146.61738	
.87000	.60000	25.00000	94.80138	178.04491	
.88000	.78000	14.00000	206.69895	199.17835	2
.89000	.73000	.00000	320.37039	.00000	
.92000	.69000	-35.00000	75.79358	-114.50041	
.95000	.58000	-82.00000	28.24422	-48.89033	
1.00000	.65000	-158.00000	10.93682	-9.27445	
1.02000	.72000	-175.00000	8.15477	-2.13439	
1.10000	.82000	147.00000	5.37484	14.66184	
.70000	.95000	105.00000	2.03648	38.33537	
.80000	.89000	73.00000	8.17598	66.93919	
.85000	.82000	43.00000	34.63917	118.25162	3
.86000	.66000	37.00000	49.70928	132.94481	
.88000	.72000	15.00000	188.93001	146.19083	

t= .635 cm.

E7375 DATE 072176 PAGE 2

.89000	.68000	.00000	262.50001	.00000	3
.91000	.64000	-30.00000	98.05824	-106.28414	
.94000	.57000	-75.00000	32.78247	-53.46913	
.97000	.62000	-128.00000	14.33263	-22.75495	
1.00000	.70000	-164.00000	8.99272	-6.81284	
1.10000	.84000	145.00000	4.77694	15.64259	
.70000	.98000	110.00000	.75276	35.01399	4
.80000	.90000	79.00000	6.47916	60.25175	
.85000	.86000	50.00000	29.44033	100.22461	
.86000	.78000	45.00000	38.75654	109.16143	
.88000	.68000	23.00000	127.70401	126.21496	
.89400	.59500	.00000	196.91358	.00000	
.91000	.54000	-35.00000	86.64464	-81.08236	
.94000	.45000	-100.00000	29.35028	-32.62062	
.99000	.70000	-170.00000	8.88923	-4.24624	
1.10000	.90000	137.00000	3.03896	19.64112	
.70000	.98000	115.00000	.71011	31.85776	5
.60000	.95000	89.00000	2.60839	50.82218	
.85000	.82000	64.00000	17.18304	77.30909	
.88000	.76000	50.00000	35.17445	96.95299	
.89000	.58000	20.00000	134.69230	80.51819	
.89900	.5[illegible]000	.00000	150.00000	.00000	
.92000	.40000	-5.00000	115.68862	-9.60159	
.96000	.58000	-157.00000	13.80182	-9.43444	
1.00000	.72000	162.00000	8.33863	7.71303	
1.10000	.90000	132.00000	3.15191	22.19617	
.70000	.98000	122.00000	.66031	27.72045	6
.80000	.90000	99.00000	4.54285	42.50912	
.85000	.84000	77.00000	11.08929	61.65697	
.88000	.64000	56.00000	42.55421	76.47941	
.89000	.50000	40.00000	77.49543	66.41057	

E7375 DATE 072176 PAGE 3

t= .635 cm.

.90000	.38000	17.00000	102.44249	26.60147	
.90400	.32000	.00000	97.05882	.00000	
.93000	.34000	-145.00000	26.43946	-11.66542	6
.94000	.44000	-177.00000	19.45593	-1.11937	
1.00000	.80000	137.00000	6.40606	19.42365	
1.10000	.96000	120.00000	3.50606	28.76967	
.70000	.99000	125.00000	.31939	26.03618	
.80000	.92000	107.00000	3.22154	36.90774	
.85000	.89000	90.00000	5.80159	49.67209	
.88000	.75000	79.00000	17.14298	57.69411	
.89000	.56000	69.00000	37.62867	57.31737	
.90000	.35000	57.00000	59.19617	39.60052	7
.91000	.21000	60.00000	54.39696	9.51628	
.93000	.40000	160.00000	21.97045	7.16337	
1.00000	.85000	122.00000	4.16750	27.57665	
1.10000	.95000	112.00000	1.86508	33.70205	
.70000	.99000	127.00000	.31376	24.93694	
.80000	.97000	114.00000	1.08261	32.46851	
.85000	.90000	98.00000	4.61136	43.26270	
.88000	.76000	95.00000	12.35259	44.28226	
.90000	.48000	100.00000	27.54679	33.84117	8
.90500	.37000	110.00000	31.05060	25.01868	
.93000	.69000	127.00000	11.35802	23.89861	
1.00000	.90000	109.00000	3.96557	35.52471	
1.10000	.95000	103.00000	2.09273	39.73828	
.70000	.99000	132.00000	.30110	22.26939	
.80000	.93000	117.00000	.69479	30.64452	
.85000	.97000	110.00000	1.13480	35.00721	9
.88000	.96000	112.00000	3.82466	33.59850	
.90000	.81000	113.00000	7.51294	32.58101	
.92500	.89000	113.00000	4.17940	32.94210	

t=.635 cm.

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.93000	.90000	109.00000	3.96557	35.52471
.95000	.92000	112.00000	3.02928	33.64915
1.00000	.95000	100.00000	2.18412	41.91727
1.10000	.98000	95.00000	.92922	45.81749

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	E7377				DATE 072176	PAGE 1
FREQUENCY	REFLECTION MAG.	REFLECTION ANG.	R	X	t = .953 cm.	
.70000	.90000	67.00000	8.58608	74.87090		
.80000	.82000	38.00000	43.10768	132.84662		
.84000	.80000	14.00000	205.67897	221.12066		
.85000	.76000	11.00000	254.10604	193.12661	1	
.86000	.72000	5.00000	375.06835	137.38428		
.86800	.75000	.00000	366.66668	.00000		
.89000	.65000	-27.00000	109.31009	-111.69872		
.92000	.60000	-52.00000	51.52158	-76.11742		
.95000	.45000	-97.00000	28.56310	-35.36498		
1.00000	.46000	-173.00000	18.55321	-2.64660		
1.10000	.67000	117.00000	13.39610	29.02619		
.70000	.94000	75.00000	4.16690	65.00433		
.80000	.84000	42.00000	32.20910	122.97498		
.85000	.78000	15.00000	192.82569	198.78792		
.86000	.76000	9.00000	276.76927	155.78158		
.87000	.70000	.00000	283.33334	.00000	2	
.89000	.60000	-30.00000	99.77232	-93.52594		
.91000	.62000	-53.00000	48.24188	-77.59934		
.95000	.49000	-112.00000	23.64355	-28.27424		
1.00000	.65000	-177.00000	10.61311	-1.25957		
1.10000	.80000	120.00000	7.37815	28.40279		
.70000	.92000	82.00000	4.83020	57.29725		
.80000	.84000	48.00000	25.32125	107.37154		
.85000	.78000	17.00000	167.99995	195.64723		
.86000	.71000	11.00000	225.03494	122.93892		
.87100	.64000	.00000	227.77779	.00000	3	
.90000	.56000	-42.00000	69.95855	-81.81992		
.95000	.48000	-130.00000	20.83077	-19.90988		
1.00000	.58000	170.00000	13.38604	4.07180		

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$t = .953$ cm

1.10000	.80000	120.00000	7.37815	28.40279	3
.70000	.96000	87.00000	2.15296	52.65271	
.80000	.84000	54.00000	20.50252	94.64531	
.85000	.72000	21.00000	138.37447	148.25498	
.87000	.62000	5.00000	194.45179	31.77277	
.87500	.57000	.00000	182.55815	.00000	
.89000	.44000	-34.00000	86.89460	-53.01989	4
.92000	.38000	-85.00000	39.68382	-35.11506	
.95000	.48000	-157.00000	18.20264	-8.87919	
1.00000	.64000	149.00000	11.77710	13.15758	
1.10000	.82000	115.00000	6.92565	31.42585	
.70000	.95000	95.00000	2.35769	45.77068	
.80000	.84000	65.00000	14.78824	76.47773	
.85000	.73000	32.00000	84.24715	122.53898	
.87000	.55000	12.00000	153.95200	50.47301	
.87900	.45000	.00000	131.81818	.00000	
.90000	.39000	-60.00000	57.59990	-32.88739	5
.93000	.35000	-160.00000	24.64609	-6.73080	
.97000	.60000	157.00000	12.98467	9.52051	
1.00000	.70000	130.00000	10.67125	22.44556	
1.10000	.85000	105.00000	6.41732	37.97610	
.70000	.96000	103.00000	1.66590	39.75392	
.80000	.88000	75.00000	8.55453	64.46058	
.85000	.65000	47.00000	53.89091	88.71413	
.87000	.42000	35.00000	84.33763	49.33195	
.88000	.24000	12.00000	80.12426	8.48390	6
.88500	.11000	.00000	62.35955	.00000	
.89000	.08000	-30.00000	57.24619	-4.60867	
.90000	.12000	-140.00000	41.12824	-6.43986	
.91000	.24000	-175.00000	30.68193	-1.36797	
.95000	.62000	137.00000	13.43503	18.46223	

t= .953cm.

1.00000	.30000	110.00000	8.23094	34.37878	
1.10000	.90000	95.00000	4.83090	45.59306	6
.70000	.96000	109.00000	1.53951	35.65121	
.80000	.59000	87.00000	6.11973	52.32362	
.85000	.72000	65.00000	26.47188	71.73114	
.88800	.30000	71.00000	50.86235	31.70686	
.90000	.30000	130.00000	30.83612	15.57855	
.95000	.79000	117.00000	8.02846	30.07146	7
1.00000	.90000	97.00000	4.68214	44.02763	
1.10000	.95000	90.00000	2.56292	49.94409	
.70000	.96000	114.00000	1.45072	32.45999	
.80000	.90000	97.00000	4.68214	44.02763	
.85000	.84000	85.00000	9.44275	53.67933	
.88000	.58000	105.00000	20.27655	34.23860	8
.90000	.68000	115.00000	13.19684	30.26050	
.95000	.90000	103.00000	4.28987	39.60133	
1.00000	.93000	90.00000	3.62289	49.87839	
1.10000	.97000	87.00000	1.60685	52.67323	
.70000	.99000	124.00000	.32233	26.59328	
.80000	.98000	110.00000	.75276	35.01399	
.85000	.89000	104.00000	4.67753	38.86067	
.88000	.90000	113.00000	3.78048	32.97141	
.91000	.92000	110.00000	3.10265	34.92877	9
.95000	.96000	105.00000	1.62110	38.35006	
1.00000	.97000	95.00000	1.40075	45.80654	
1.10000	.99000	95.00000	.46231	45.82396	

t= 1.27 cm.

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FREQUENCY	REFLECTION MAG.	REFLECTION ANG.	R	X	
.70000	.92000	50.00000	11.57468	106.20622	
.80000	.82000	22.00000	107.91297	202.34729	
.81000	.82000	15.00000	185.57174	240.41135	
.83000	.78000	3.00000	387.43592	80.76584	
.83500	.77000	.00000	384.78265	.00000	1
.85000	.75000	-6.00000	309.33984	-110.84843	
.90000	.58000	-52.00000	53.33299	-73.45835	
.95000	.37000	-130.00000	26.76442	-17.58270	
.97000	.40000	-175.00000	21.46220	-1.78925	
1.00000	.44000	146.00000	20.96728	12.80091	
1.10000	.78000	90.00000	12.17591	48.50463	
.70000	.92000	57.00000	9.09875	91.40385	
.80000	.81000	27.00000	80.86966	172.92786	
.82000	.78000	10.00000	271.58994	187.85038	
.83000	.77000	4.00000	359.30891	94.80209	
.84000	.75000	.00000	350.00000	.00000	
.88000	.56000	-35.00000	86.64464	-81.08236	2
.90000	.50000	-55.00000	55.44669	-60.55394	
.95000	.37000	-140.00000	25.33124	-13.96537	
1.00000	.44000	150.00000	20.61815	11.25636	
1.10000	.72000	96.00000	14.43108	42.91397	
.70000	.95000	60.00000	5.11927	86.38824	
.80000	.80000	28.00000	79.21212	165.26027	
.82000	.71000	12.00000	215.37896	128.21030	
.83000	.70000	5.00000	267.50285	63.99236	
.84000	.68000	.00000	262.50001	.00000	3
.86000	.51000	-20.00000	120.85373	-55.10594	
.90000	.40000	-70.00000	47.38967	-42.40881	
.95000	.33000	-172.00000	22.55183	-2.79536	

t=1.27cm

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1.00000	.56000	130.00000	16.87914	21.10320	
1.10000	.74000	92.00000	12.95433	46.58790	3
.70000	.91000	67.00000	7.69662	75.00574	
.80000	.83000	38.00000	47.48074	129.90647	
.82000	.72000	20.00000	145.74407	149.02753	
.83000	.70000	12.00000	211.46779	120.67783	
.84000	.68000	8.00000	232.46137	81.83363	
.85500	.60000	.00000	200.00000	.00000	4
.88000	.38000	-40.00000	76.09884	-43.44534	
.90000	.30000	-75.00000	48.68321	-31.00372	
.93000	.29000	-165.00000	27.85105	-4.57089	
.98000	.50000	140.00000	18.60259	15.94916	
1.10000	.80000	90.00000	10.97771	48.78983	
.70000	.95000	75.00000	3.45636	65.05679	
.80000	.8[illegible]000	30.00000	70.78059	157.27237	
.82000	.70000	30.00000	91.88573	126.10337	
.84000	.6[illegible]000	15.00000	159.30000	77.29657	
.85000	.55000	11.00000	156.59725	47.11702	
.86000	.46000	.00000	116.66667	.00000	5
.89000	.15000	-70.00000	53.13361	-15.32271	
.91000	.20000	-160.00000	33.90239	-4.83601	
.95000	.50000	135.00000	19.16298	18.07235	
1.00000	.70000	104.00000	13.94675	37.15007	
1.10000	.81000	84.00000	11.56769	54.19201	
.70000	.93000	83.00000	4.12421	56.35593	
.80000	.8[illegible]000	55.00000	24.92659	90.74200	
.82000	.7[illegible]000	42.00000	56.72826	104.18951	
.84000	.56000	31.00000	97.07705	81.57325	6
.86000	.38000	28.00000	90.37938	37.68526	
.88000	.18000	90.00000	49.01181	9.90137	
[illegible]	[illegible]	1[illegible].00000	35.74404	12.66366	

$t = 1.27$ cm.

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.95000	.65000	107.00000	16.02126	34.49175	6
1.00000	.80000	87.00000	11.56843	51.34425	
1.10000	.90000	75.00000	7.06929	64.68734	
.70000	.95000	90.00000	2.56292	49.94409	7
.80000	.84000	68.00000	13.67992	72.37604	
.85000	.50000	55.00000	55.44669	60.55394	
.86500	.40000	70.00000	47.38967	42.40881	
.88000	.39000	104.00000	31.62326	28.22833	
.90000	.55000	105.00000	21.97601	33.47864	
1.00000	.96000	77.00000	6.76256	62.42192	
1.10000	.92000	68.00000	6.63860	73.72976	
.70000	.98000	97.00000	.90047	44.23765	8
.80000	.89000	80.00000	7.01086	59.11187	
.83000	.76000	70.00000	19.97142	67.52899	
.85000	.65000	77.00000	25.55647	56.05306	
.87000	.59000	92.00000	17.18850	45.24879	
.90000	.89000	95.00000	5.33934	45.54128	
.95000	.90000	87.00000	5.53789	52.39182	
1.00000	.95000	72.00000	3.70699	68.69961	
1.10000	.98000	67.00000	1.65787	75.52845	
.70000	.96000	109.00000	.76210	35.66813	9
.80000	.92000	96.00000	3.76776	44.88830	
.85000	.89000	92.00000	5.60721	47.97892	
.87000	.90000	99.00000	4.54285	42.50912	
.90000	.96000	95.00000	4.83090	45.59306	
.95000	.96000	90.00000	1.01020	49.99961	
1.00000	.97000	79.00000	1.88168	60.63073	
1.10000	.95000	77.00000	2.63197	62.80191	

Appendix VII

Field Data

600 MHZ t = 1/4 Field Measurements

f = 548 MHZ

Feed Location From Center of Disc	Probe Location	Magnitude (mv)	Phase	Magnitude Normalized	Phase Normalized
14.12 cm. (Edge Feed)	11.55	.435	+120	1	0
	9.99	.410	+110	.943	-10
	8.56	.275	+105	.632	-15
	7.13	.246	+95	.552	-25
	5.71	.165	+60	.379	-60
	4.29	.135	+25	.31	-95
	2.86	.110	-10	.253	-130
	1.43	.076	-45	.175	-165
	1.06	.230	-60	.529	-180
	2.81	.285	-80	.655	-200
	4.71	.40	-70	.92	-190
	6.4	.45	-20	1.03	-140
	8.15	.52	+10	1.195	-110
11.483	14.51	.9	-15	4.09	-45
	8.62	.22	+30	1	0
	7.2	.13	+35	.59	+5
	5.78	.12	+55	.54	+25
	4.36	.115	+130	.523	+100
	2.94	.110	+160	.5	+130
	1.52	.09	+270	.4	+140
	.86	.095	-120	.43	-150
	2.60	.14	-100	.63	-130
	4.50	.19	-90	.86	-120
	6.09	.225	-50	1.02	-80
	7.84	.35	-30	1.59	-60
8.664	13.9	2.5	-30	.27	+10
	12.79	2.6	-60	.28	-20
	11.68	2.5	-30	.27	+10
	10.09	2.7	-15	.29	+25
	5.81	9.2	-40	1	0
	4.38	9.1	-45	.989	-5
	2.95	6.6	-180	.72	-140
	1.52	1.35	-215	.146	-175
	.86	6.4	-220	.695	-180
	2.6	7.8	-160	.84	-120
	3.72	8.3	-135	.902	-95
	5.31	10.0	-100	1.08	-60

600 MHZ t = 1/4 Field Measurements

f = 548 MHZ

Feed Location From Center of Disc	Probe Location	Magnitude (mv)	Phase	Magnitude Normalized	Phase Normalized
5.76 cm.	13.86	4.7	+5	.57	+10
	12.75	3.4	-80	.41	-75
	11.63	1.35	-40	.165	-35
	10.20	4.0	+30	.48	+45
	8.62	11.0	0	1.34	+5
	2.90	8.2	-5	1	0
	1.47	7.2	-100	.878	-95
	.907	1.45	-160	.176	-155
	2.65	8.4	-150	1.02	-145
	4.56	10.5	-100	1.22	-95
	6.15	13.5	-95	1.64	-90
	7.90	14.5	-60	1.76	-55
2.88 cm.	14.5	4.6	-150	1.27	-255
	13.04	3.0	-160	.833	-265
	11.42	1.0	-135	.278	-240
	10.02	2.8	-60	.77	-165
	8.6	6.8	+25	1.88	-80
	7.16	7.5	+20	2.08	-85
	5.74	7.7	+10	2.1	-95
	4.31	6.7	-50	1.86	-155
	.49	3.6	+105	1	0
	1.25	2.5	+145	.69	+30
	3.16	1.1	+150	.305	+35
	4.74	2.4	+155	.67	+40
	6.49	2.65	+160	.736	+45

600 MHZ t = 3/8 Field Measurements

f = 538 MHZ

Feed Point Location From Center of Disc	Probe Location	Magnitude (mv)	Phase	Magnitude Normalized	Phase Normalized
14.12 cm.	11.55	.330	+150	1	0
	9.99	.290	+138	.878	-12
	8.56	.245	+115	.742	-35
	7.13	.225	+90	.682	-60
	5.71	.220	+80	.67	-70
	4.29	.155	+60	.469	-90
	2.86	.150	0	.45	-150
	1.43	.100	-70	.30	-220
	1.06	.195	-55	.59	-205
	2.81	.215	-40	.652	-190
	4.71	.240	-25	.727	-175
	6.4	.280	-5	.848	-155
	8.15	.340	+15	1.03	-135
11.483 cm.	14.51	.135	+130	.6	+25
	8.62	.225	+105	1	0
	7.2	.185	+135	.822	+30
	5.78	.175	+145	.798	+40
	4.36	.160	+75	.71	-30
	2.94	.130	+40	.578	-65
	1.52	.115	-65	.511	-170
	.86	.076	-110	.338	-215
	2.60	.125	-115	.556	-220
	4.5	.135	-140	.6	-245
	6.09	.175	-80	.778	-185
	7.89	.180	-35	.8	-140
8.66 cm.	13.9	.43	+80	.374	-45
	12.8	.22	+60	.191	-65
	11.7	.28	+110	.24	-15
	10.1	.35	+120	.304	-5
	5.8	1.15	+125	1	0
	4.38	.64	+150	.556	+25
	2.95	.37	-165	.32	-290
	1.52	.23	-150	.2	-275
	.86	.56	-130	.487	-255
	2.6	.82	-120	.713	-245
	3.72	.94	-105	.82	-225
	5.31	1.65	-60	1.4	-185

600 MHZ t = 3/8 Field Measurements

f = 538 MHZ

Feed Point Location From Center of Disc	Probe Location	Magnitude (mv)	Phase (Degrees)	Magnitude Normalized	Phase Normalized
5.76 cm.	13.86	2.7	+60	1.08	+210
	12.75	2.0	+85	.8	+235
	11.63	1.7	-170	.68	-20
	10.2	4.4	-140	1.76	+10
	8.62	5.7	-130	2.28	+20
	2.9	2.5	-150	1	0
	1.47	2.4	+30	.96	+180
	.907	.85	+20	.34	+170
	2.65	2.0	+5	.8	+155
	4.56	2.2	0	.88	+150
	6.15	2.8	-130	1.12	+20
	7.9	4.5	-170	1.8	-20
2.88 cm.	14.5	1.35	-95	.586	-20
	13.05	.80	-75	.34	0
	11.42	.83	+50	.36	+125
	10.02	.74	+90	.32	+165
	8.6	1.50	+110	.652	+185
	7.16	2.1	+120	.91	+195
	5.74	2.4	+125	1.04	+200
	4.31	2.5	+155	1.08	+230
	.49	2.3	-75	1	0
	1.25	1.85	-20	.804	+55
	3.16	.036	-25	.156	+50
	4.74	1.45	-30	.63	+45
	6.49	2.2	+20	.957	+95

600 MHZ t = 1/2 Field Measurements

f = 538 MHZ

Feed Point Location From Center of Disc	Probe Location	Magnitude (mv)	Phase (Degrees)	Magnitude Normalized	Phase Normalized
14.12 cm.	11.55	.205	+80	1	0
	9.99	.20	+100	.976	+20
	8.56	.165	+110	.905	+30
	7.13	.145	+90	.707	+10
	5.71	.105	+60	.512	-20
	4.29	.086	+25	.419	-55
	2.86	.082	-30	.4	-110
	1.43	.076	-55	.37	-135
	1.06	.080	-75	.39	-155
	2.81	.084	-100	.409	-180
	4.71	.1	-110	.487	-190
	6.4	.13	-90	.63	-170
	8.15	.15	-65	.73	-145
11.483 cm.	14.51	.7	-20	.56	-130
	8.62	1.25	+110	1	0
	7.2	1.05	+80	.84	-30
	5.78	.9	+60	.72	-50
	4.36	.88	+45	.704	-65
	2.04	.55	+15	.44	-95
	1.52	.18	-5	.144	-115
	.86	.64	-25	.512	-135
	2.6	.74	-80	.592	-195
	4.5	1.2	+40	.96	-70
	6.09	1.22	+70	.976	-90
	7.89	1.25	+80	1	-30
8.66 cm.	13.9	.88	+12	.47	-33
	12.8	.62	+60	.33	+15
	11.7	.82	+140	.44	+95
	10.1	.95	+70	.51	+25
	5.8	1.85	+45	1	0
	4.38	1.70	-10	.919	-55
	2.95	1.55	-55	.838	-100
	1.52	.95	-75	.51	-120
	.86	.44	-70	.23	-115
	2.6	1.10	-50	.594	-95
	3.72	1.2	-45	.648	-90
	5.31	1.35	-20	.729	-65

600 MHZ t = 1/2 Field Measurements

f = 526 MHZ

Feed Point Location From Center of Disc	Probe Location	Magnitude (mv)	Phase (Degrees)	Magnitude Normalized	Phase Normalized
5.76 cm.	13.86	1.4	-50	1	-150
	12.75	.84	-15	.6	-115
	11.63	1.15	+70	.82	-30
	10.2	2.8	+155	2	+55
	8.62	3.3	+125	2.35	+25
	2.9	1.4	+100	1	0
	1.47	1.35	+65	.96	-35
	.907	1.2	+40	.857	-60
	2.65	1.05	-40	.75	-140
	4.56	1.35	-50	.96	-150
	6.15	2.05	-60	1.46	-160
	7.9	2.15	-50	1.54	-150
2.88 cm.	14.5	1.55	0	.43	-160
	13.05	1.4	-95	.38	-255
	11.42	1.35	-50	.375	-210
	10.02	.80	-20	.22	-180
	8.6	.60	-10	.167	-170
	7.16	.70	+5	.19	-155
	5.74	1.20	+45	.33	-115
	4.31	1.3	+140	.36	-20
	.49	3.6	+160	1	0
	1.25	2.35	+140	.65	-20
	3.16	1.0	+120	.278	-40
	4.74	.64	+20	.168	-140
	6.49	1.4	-25	.388	-165

1 GHZ t = 1/4 Field Measurements

f = 890 MHZ

Feed Point Location From Center of Disc	Probe Location	Magnitude (mv)	Phase (Degrees)	Magnitude Normalized	Phase Normalized
8.38 cm.	6.74	.57	+130	1	0
	5.32	.4	+120	.7	-10
	3.89	.2	+100	.35	-30
	2.47	.18	0	.31	-130
	1.11	.48	-30	.84	-160
	.395	.58	-35	1.02	-165
	1.826	.86	-40	1.51	-175
	3.254	.98	-30	1.72	-160
6.15 cm.	8.65	8.2	+135	.61	+5
	3.3	13.5	+130	1	0
	1.87	6.4	-10	.47	-140
	.49	5.6	-30	.41	-160
	.99	2.1	-40	.156	-170
	2.42	3.3	-35	.24	-165
	4.8	4.8	-15	.35	-145
	8.45	25.0	-10	1.85	-140
4.37 cm.	8.66	4.2	+180	.145	+130
	7.22	6.4	+160	.22	+110
	1.52	29	+50	1	0
	.09	28	+35	.965	-15
	1.345	7.8	+30	.268	-20
	3.72	5.8	+25	.2	-25
	7.37	20.5	-50	.71	-100
	8.7	21.0	-25	.72	-75
2.56 cm.	8.28	4.0	-100	.4	-160
	6.84	2.1	-80	.21	-140
	5.41	2.4	+35	.24	-25
	.29	10.0	+60	1	0
	2.68	3.5	+50	.35	-10
	6.33	1.35	-100	.13	-160
	7.91	6.0	-120	.6	-180
1.651 cm.	8.7	4.0	-115	.38	-170
	7.35	1.8	-110	.17	-165
	5.93	5.0	+30	.476	-25
	4.5	6.2	+50	.59	-5
	.729	10.5	+55	1	0
	4.3815	1.85	+25	.176	-30
	5.969	1.9	-100	.18	-155

1 GHZ   t = 3/8   Field Measurements

f = 870 MHZ

Feed Point Location From Center of Disc	Probe Location	Magnitude (mv)	Phase (Degrees)	Magnitude Normalized	Phase Normalized
8.38 cm.	6.74	1.35	+180	1	0
	5.32	1.05	+170	.78	-10
	3.89	.75	+150	.55	-30
	2.47	.42	+100	.31	-80
	1.11	.6	+65	.44	-115
	.395	1.0	+30	.74	-150
	1.83	1.35	+20	1	-160
	3.25	1.45	-10	1.07	-190
6.15 cm.	8.65	1.35	0	1.29	-45
	3.3	1.05	+45	1	0
	1.87	.75	-40	.71	-85
	.44	.42	-60	.4	-105
	.99	.6	-70	.57	-115
	2.42	1.00	-120	.95	-165
	8.45	1.35	-100	1.29	-145
4.37 cm.	8.66	7.8	+50	.312	-25
	7.22	4.4	+65	.176	-10
	1.52	25	+75	1	0
	.09	23.5	0	.94	-75
	1.345	22	-75	.88	-150
	3.72	6.8	-70	.272	-145
	7.37	5.1	-65	.204	-140
	8.7	13.0	-60	.52	-135
2.56 cm.	8.28	5.2	-5	.325	-155
	6.84	3.0	+20	.188	-130
	5.41	3.4	+135	.212	-15
	.29	16	+150	1	0
	2.68	11	-140	.6875	-290
	6.33	1.5	+25	.093	-125
	7.91	4.2	-25	.262	-175
1.651 cm.	8.7	.34	-30	.34	+5
	7.35	.18	-150	.18	-115
	5.93	.24	-40	.24	-5
	4.5	.64	-25	.64	+10
	.729	1.0	-35	1	0
	4.3815	.205	-145	.205	-110
	5.969	.18	+160	.18	+195

1 GHZ   t = 1/2   Field Measurements

f = 834 MHZ

Feed Point Location From Center of Disc	Probe Location	Magnitude (mv)	Phase (Degrees)	Magnitude Normalized	Phase Normalized
8.38 cm.	6.74	.90	+30	1	0
	5.32	.70	-50	.78	-80
	3.89	.46	-60	.51	-90
	2.47	.22	-70	.24	-100
	1.11	.2	-75	.22	-105
	.395	.64	-105	.71	-135
	1.83	.70	-160	.78	-190
	3.254	.94	-140	1.044	-170
6.15 cm.	8.65	.7	-50	.74	-80
	3.3	.94	+30	1	0
	1.87	.90	+20	.957	-10
	.44	.7	-50	.74	-80
	.99	.64	-60	.68	-90
	2.42	.40	-70	.43	-100
	4.8	.46	-90	.49	-120
	8.45	.60	-100	.64	-130
4.37 cm.	8.66	2.3	-55	.177	-125
	7.22	4.2	-30	.32	-100
	1.52	13.0	+70	1	0
	.09	12.5	+60	.96	-10
	1.345	6.9	+40	.53	-30
	3.72	12.0	-10	.92	-80
	7.37	12.5	-30	.96	-100
	8.7	20	-60	1.53	-130
2.56 cm.	8.28	2.8	-10	.29	-155
	6.84	1.5	+25	.159	-120
	5.41	2.8	+140	.29	-5
	.29	9.4	+145	1	0
	2.68	7.0	+130	.74	-15
	6.33	.84	+40	.89	-105
	7.91	2.4	-30	.25	-175
1.651 cm.	8.7	1.0	-85	.09	-180
	7.35	.32	-40	.02	-135
	5.93	1.0	+75	.09	-20
	4.5	2.3	+85	.21	-10
	.729	11.0	+95	1	0
	4.3815	1.0	+70	.09	-25
	5.97	.42	-20	.03	-95